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Physical Countermeasures to Sustain Acceptable Living and Working Conditions in Radioactively Contaminated Residential Areas

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Abstract The Chernobyl accident highlighted the need in nuclear preparedness for robust, effective and sustainable countermeasure strategies for restoration of radioactively contaminated residential areas. Under the EC-supported STRATEGY project a series of investigations were made of countermeasures that were deemed potentially applicable for implementation in such events in European Member States. The findings are presented in this report, in a standardised datasheet format to clarify the features of the individual methods and facilitate intercomparison. The aspects of averted doses and management of wastes generated by countermeasures had to be described separately to provide room for the required level of detail. The information is mainly intended as a tool for decision makers and planners and constitutes a basis for the STRATEGY decision framework for remediation of contaminated urban areas.

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Summary

Following a major nuclear accident, residential areas may be contaminated for many years, resulting in a multitude of economic, social and health-related penalties to the affected population. The implementation of robust, effective and holistic restoration strategies for these areas may be a requirement in sustaining acceptable living and working conditions. The STRATEGY project was launched within the European Commission's 5th Framework Programme with the ultimate goal of constructing a decision framework, which could be used by planners in connection with the selection of such remediation strategies for European Member States. In this context a need was identified for a comprehensive investigation of the various potentially applicable countermeasures. It was decided to report the findings of this investigation in a special datasheet format, which would clarify the various factors that would determine the feasibility of applying each countermeasure in a restoration strategy for a contaminated area.

The datasheets in this report represent a further development of previously developed databases, including new and updated technical data and a greater level of detail. One of the novel features of the STRATEGY database is the inclusion of social, psychological, ethical, legal and communication aspects, which have previously only been given limited consideration in reports outlining potential countermeasure options. A total of 27 countermeasures were found to be of possible relevance to urban contamination situations in European Member States, and these are described. The countermeasures are designed for treatment of different types of contaminated surface in the inhabited environment (streets, pavements, walkways, areas of soil of varying size, vegetation, snow-covered areas, walls, roofs and indoor surfaces of dwellings).

The justification and optimisation of urban countermeasure strategies strongly depends on case-specific parameters. For instance, average external doses (and thereby possibly averted doses by implementation of countermeasures) to persons living in different types of dwellings may deviate by as much as a factor of 10. Therefore, a methodology for evaluation of these doses in different urban environments has been included in a special section of this report. Also direct implementation costs (e.g., need for special equipment) and indirect costs (e.g., loss of value of an area) of countermeasure implementation can vary greatly according to the particular situation.

One of the cost elements that will arise after a decontamination has been carried out is that associated with the management of the waste generated by the countermeasures. These costs must be regarded as an inherent part of a countermeasure strategy, and descriptions of recommendable waste management options are therefore also included in this report.

The work has been reviewed outside the STRATEGY project group by groups of potential users and 'stakeholders' (representatives of individuals or organisations that would in some way be involved in parts of the implementation of a countermeasure strategy), and subsequently independently peer reviewed.

Contents

Preface

The work described in this report was carried out under the STRATEGY project supported by the Commission of the European Communities under the 'Research and Training Programme in the field of nuclear energy' of the 5th Framework Programme (Contract FIKR-CT-2000-00018). A main objective of the STRATEGY project is to identify and describe countermeasures for sustainable restoration and long-term management of rural, urban and industrial ecosystems contaminated as a result of a nuclear accident. The findings are to be implemented in a system that can be used to facilitate efficient decision-making in the event of a nuclear accident. Further details of the STRATEGY project can be found on http://www.strategy-ec.org.uk/.

The contributions to this report of each of the authors are specified below:

K.G. Andersson & J. Roed: are the principal report authors and authors of all parts of the countermeasure descriptions in this report unless specified otherwise below. J. Roed also contributed to the sections on ethical, legal, social and communication aspects in the countermeasure descriptions.

K. Eged, Z. Kis, G. Voigt & R. Meckbach: are the principal authors of Chapter 4 on external doses and provided valuable comments to other sections.

D.H. Oughton, J. Hunt & R. Lee: are the authors of the sections on ethical, legal, social and communication aspects in the countermeasure descriptions and provided valuable comments to other sections.

N.A. Beresford, F.J. Sandalls & A.F. Nisbet: provided valuable comments and revision of the various report sections.

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1 Introduction

1.1 General background

In the various member states of the European Union, radiological preparedness is organised in very different ways. In many of these countries the responsibility for decision-making, including decisions related to implementation of countermeasures, rests within authority organisations at a national level. However, for instance in Sweden, such decisions are taken on a regional basis by district councils ('länsstyrelser'), which may seek guidance and advice from central government bodies.

In the event of a major nuclear accident leading to contamination of large urban areas, the responsible decision-makers will, regardless of the structure of the preparedness organisations, be confronted with a host of questions and demands from, e.g., representatives of the affected populations and the press. It is under this pressure that the first decisions will have to be made on whether or not to intervene to reduce doses to affected populations. The long-term (external) dose in an urban area after a major nuclear accident is likely to be dominated by the radiocaesium isotopes ^{134}Cs and, particularly, ^{137}Cs (Andersson & Roed, 1999). Countermeasures for reduction of long-term doses may often be effectively implemented over a comparatively long period of time following an accident, as contributions to long-term dose received over the first months do not constitute a major part of the total dose integrated over, for instance, 70 years in most cases. However, to be efficient, some countermeasures, which can greatly affect long-term doses, need to be carried out as soon as possible after the contamination has occurred. An example of this is lawn mowing (and removal of the cut grass), which can in some cases, if applied early, prevent substantial long-term doses from contaminants that would otherwise be transferred to the underlying soil. As limited resources would be available, it is important that countermeasures are selected and applied optimally as a part of a holistic restoration strategy for the area. It is therefore advantageous if decisions on countermeasure strategies for reduction of long-term doses (though not necessarily their implementation) can be made at an early stage. However, it is even more important to ensure that the right countermeasures are introduced in a particular situation. If applied wrongly, some countermeasures could well do more harm than good, and the effect would often be irreversible.

In order to speed up the decision making process and at the same time ensure that potentially important issues are not overlooked in the process of optimisation, it is of great importance that decision-makers have access to systematic descriptions of the potentially applicable countermeasures for reduction of dose in the residential environment in advance of an accident. These descriptions should provide an overview of methods and factors affecting their application in a standardised format that facilitates intercomparison. The descriptions would allow the planners to assess in time whether some countermeasures would be likely to be more suitable/acceptable than others given the specific conditions in the area, e.g., with respect to topography, building tradition and soil type. Further, the descriptions would show local planners which equipment, consumables, skilled personnel, etc. must be available to carry out the countermeasures, and the availability in the local area of these resources could thus be assessed/secured prior to any emergency. Finally, first steps in the preparations for public interaction (information/dialogue) could be planned.

Recognising these needs, a first effort was made in the ECP-4 project supported by the European Commission to systematically describe restoration methods for contaminated urban, agricultural/rural and forested areas in a series of data sheets (Roed et al., 1995). These descriptions focused on the direct costs and efficiency in dose reduction of the various countermeasures and provided information on the type and amount of wastes (if any) that would be generated. For this suite of data sheets it was decided to express estimates of the required labour costs in units of time, as wages will vary considerably, both temporally and between countries/regions. In a later investigation in the EKO-5 project supported by Nordic Nuclear Safety Research (NKS), the data were updated with more recent findings and complemented with fuller descriptions of the countermeasures (Andersson, 1996; Andersson & Roed, 1999). A novelty in the EKO-5 database was the introduction of estimates of external dose in a number of types of contaminated urban environments, ranging from detached single-family houses to blocks of flats. The dose estimates were made assuming respectively wet and dry deposition, using the URGENT model (Andersson et al., 1995). The EKO-5 database was implemented in 1998 as part of a preparedness CD ROM created for the Swedish Rescue Service on restoration of contaminated urban areas. At this stage, several Swedish district councils had already implemented the information in their preparedness plans. The data were also implemented in an IAEA guide on decontamination of rural settlements (Andersson et al., 2001).

1.2 The STRATEGY project database

In 2000, the EC-STRATEGY project was launched (Howard et al, 2002). The overall objective of this project is to develop a decision framework for the selection of robust and practicable remediation strategies for European Member States, enabling sustainable management of contaminated urban, industrial, and agricultural areas. A requirement in this context was found to be the creation of a database describing the methods that would be considered to be relevant and practicable in at least some areas of the European Member States. Whereas the intervention justification and optimisation facilitated by previous databases has practically been limited to a balancing of direct intervention costs against averted dose, the STRATEGY database is aimed at providing a full overview of elements of cost and benefit that might arise due to the implementation of a restoration strategy.

This type of optimisation is clearly in line with the principles recommended in 2000 by the International Commission on Radiological Protection (ICRP, 2000). The ICRP emphasised that although 'the immediate advantage of intervening in a prolonged exposure situation is the expectation of obtaining averted (individual and collective) doses…', also other advantages must enter the decision matrix. These include 'the consequent reassurance gained by the population and the decrease in anxiety created by the situation'. It is further stated that 'disadvantages introduced by the intervention include costs, harm and social disruption associated with it. If the advantages of intervening offset the disadvantages, the net benefit of intervening will be positive and the intervention is said to be justified. The optimum protection option is not necessarily the option that results in the lowest residual annual doses, either individual or collective dose. Some options could result in a lower residual annual dose but give a smaller net benefit than the optimum option'.

Some of the 'new' perspectives in the STRATEGY database that would need to be considered in a holistic evaluation of countermeasure options are legal considerations, public perceptions and communication of technical information, as well as social, ethical and environmental impact. One of the lessons learned from the handling of the Chernobyl accident was, according to the EC-TACIS project ENVREG9602, that the psychological stress connected with a nuclear contamination of inhabited areas may be considered to be more harmful than the radiation. This implies that the ways in which introduction of dose reductive countermeasures may be perceived by the public constitute a crucial factor in connection with the choice of intervention. It also stresses the need for dialogue between experts and the affected population in order to properly understand the social and psychological factors at play in particular localities.

Further, on the technical side, new countermeasure investigations have been made improving the state of knowledge compared with earlier databases (Roed et al., 1998; Fogh et al., 1999; Andersson et al, 2001). Also new investigations of the behaviour of contaminants in the urban environment have been performed (Andersson et al., 2002), which together with Monte Carlo calculations performed within the STRATEGY project of urban dose in typical European dwelling areas led to an improved methodology for prediction of particularly the long-term doses.

Throughout the first months of the STRATEGY project, the partners developed a database template for the description of each of the countermeasures that would be considered (see below). To help the reader to better understand the headings of the various sections and information provided in this template (as given in the left column of the template below), general explanations are given in the right column of the template below.

The completed data sheets were commented on by the other STRATEGY project partners and peer-reviewed by an independent expert in the field. In the STRATEGY project there is an 'end user' group (consisting of representatives of decision makers and regulators who may actually use the project results). The dialogue with this group, e.g., through meetings, ensured incorporation of viewpoints from the user community in the development of the database system. The overall conclusion of the end user evaluation of the database was that the project output seemed sensible and worthwhile. The urban part of the database was also discussed with two 'stakeholder' representatives (representatives of individuals or organisations that would in some way be involved in parts of the implementation of a countermeasure strategy). One of these represented the authority viewpoints, whereas the other had a practical background and experience from having carried out a number of the countermeasures in industry and at nuclear power plants as well as in the areas of the Former Soviet Union contaminated by the Chernobyl accident. This interaction enabled a number of improvements of the data sheets, and the 'stakeholder' representatives concluded that the database would be of great value to decision-makers.

Name of countermeasure	
Objective	Here the primary aims of the action are specified (e.g., reduction of external or internal dose).
Other Benefits	Here the secondary aims of the action are expressed (if any). For instance, the primary objective may be reduction of external dose, whereas an additional benefit may be a limited reduction in internal dose.
Countermeasure description	Here a short description is given of the principles of the countermeasure.
Target	The type of object, on/to which the counter-measure is to be applied, is specified here.
Targeted radionuclides	Here it is stated which contaminant radionuclides the countermeasure is primarily aimed at.
Scale of application	Here a rough indication is given of whether it is considered realistic/recommendable to apply the countermeasure on a large or small scale over the contaminated area.
Contamination pathway	This term is here defined as the relevant process(es), where a countermeasure reduces the transfer of contaminants to humans, e.g., through various foodchain steps or by inhalation. As food products are only to a limited extent produced in urban areas, the term is not applicable to most urban countermeasures. However, for instance, ploughing and digging procedures may reduce the uptake of contamination to edible kitchen garden plants from soil, and if such plants are grown in the area, the relevant contamination pathway for this type of countermeasure would therefore be the contaminant soil-to-plant-transfer.

Exposure pathway	This term is here defined as the mechanism(s) through which a person may be exposed as a result of the contamination on/in the target on/to which the countermeasure is to be applied. For instance, a ploughing or digging procedure may reduce the external exposure to persons spending time in or around the ploughed area, and at the same time reduce transfer of contaminants from soil to crops subsequently grown in the area, thereby also reducing internal exposure to consumers. The relevant exposure pathways for this type of countermeasure are therefore external and internal exposure. Since edible crops are only to a limited extent grown in urban areas, the most important exposure pathway is here generally likely to be the external.
Time of application	This gives an indication of the recommended time interval for application of the countermeasure. Some countermeasures must be implemented relatively quickly to be efficient, whereas other may ideally be applied at a later stage.
Constraints:	In this section, various types of restrictions on countermeasure application are stated.
Legal constraints	Legal constraints may be determined by, e.g., regulation, nature protection, cultural heritage protection and political concerns.
Social constraints	Social constraints include the acceptability of the countermeasure to e.g., the affected population or clean-up workers. Constraints could also be determined by for instance NGO response or animal welfare.
Environmental constraints	These are primarily constraints of physical nature in the environment, such as snow, frost, soil types, slopes and structure of land.
Communication constraints	The needs for public explanation and dialogue in selection of countermeasures are stressed here.
Effectiveness:	In this section, the effectiveness of the method in eliminating the targeted contamination is estimated together with factors that may influence this value.
Countermeasure effectiveness	This is an estimate of the effectiveness of the method in eliminating the targeted contamination problem.
Factors influencing effectiveness of procedure (Technical)	Any technical factors that may under different circumstances influence the effectiveness of the method are listed here.
Factors influencing effectiveness of procedure (social)	'Social' factors that may under different circumstances influence the effectiveness of the method are listed here (e.g., whether the method is fully understood by workers).
Feasibility:	This section describes what is required to carry out the countermeasure.
Required specific equipment	The primary equipment for carrying out the countermeasure is mentioned here.
Required ancillary equipment	Any secondary equipment that may be required in connection with the countermeasure implementation (e.g., ladders or scaffolding) is mentioned here.
Required utilities and infrastructure	Required utilities may for instance be water supplies, power supplies or transport roads.

Required consumables	Required consumables may, according to the specific countermeasure, include, e.g., gasoline or fertilisers.
Required skills	The required skills or needs for training of operators are stressed here.
Required safety precautions	These are the operator safety precautions that are deemed necessary in connection with the implementation of the countermeasure.
Other limitations	If there are feasibility limitations that are not covered under other headings, these are mentioned here.
Waste:	Some countermeasures create waste, which may need special handling. This section is aimed at providing an overview of the waste problem.
Amount and type	The waste is here described with respect to, e.g., volume, wet/dry fractions and expected relative level of contamination per unit of volume.
Possible transport, treatment and storage routes.	This is in reality a reference/link to a special text section (see Chapter 3) with relatively long descriptions of what can be done about the particular type of waste in terms of transport, treatment and storage/ disposal.
Factors influencing waste issues	Any factors that may under different circumstances influence the way that wastes are dealt with are listed here. Two examples are public acceptability and legal feasibility of the waste treatment /storage route.
Doses:	This section describes how the countermeasure leads to changes in various dose contributions.
Averted dose	This is in reality a reference/link to a special text section (see Chapter 4) with detailed descriptions of doses that can be averted under different circumstances. The doses that can be averted by a countermeasure strongly depend on the scenario (e.g., type of environment).
Factors influencing averted dose	An overview is here given of other factors than the countermeasure effectiveness, which may influence the magnitude of the averted dose (e.g., behaviour pattern, population density).
Additional dose	A description is here given of any extra doses that may be received, e.g., by workers in connection with the implementation of the countermeasure.
Intervention Costs:	This section describes the costs that may be foreseen in direct connection with the intervention.
Equipment	These are the costs of the required primary equipment.
Consumables	These are the costs of the required consumables (given per unit of the target that is treated).
Operator time	This is the time consumption that is expected per unit of the target that is treated.
Factors influencing costs	Such factors may for instance be the wage level in the area, the size of the target to be treated (e.g., need for scaffolding) or the need for import of equipment into the area.
Communication costs	These are the foreseen costs for the required public information and dialogue in connection with implementation of the countermeasure.
Compensation costs	This could be compensation to the public or to owners of objects that are damaged in connection with the implementation of the countermeasure.

Waste cost	This is the cost associated with the handling of waste problems (if any). It will depend on the choice of handling options outlined under the above 'Waste' descriptions.
Assumptions	Any other assumptions made, which might significantly influence the intervention costs are mentioned here.
Side-effect evaluation:	This section provides descriptions of the indirect effects that the countermeasure application may have on the area.
Ethical considerations	A description of possible positive and negative ethical aspects is given here. For instance that countermeasures may promote self-help or require informed consent of workers.
Environmental impact	A description of the impact that a countermeasure may have on the environment (e.g., with respect to biodiversity or wildlife reserves) is given here.
Agricultural impact	This is an account of the impact that a countermeasure may have on the future applicability of the area in agriculture. For instance, a countermeasure may reduce the soil fertility in the area.
Social impact	A social impact of a countermeasure may for instance be the requirement for change in behaviour or social activity, or effects in social relationships such as trust in institutions or disputes over prioritisation of targets to be treated in the area.
Other side effects, pos. or neg.	Some countermeasures may have other side effects. For instance, some methods for treatment of walls also clean the walls and give them a nicer appearance. However, some countermeasures could damage the target.
Practical experience	Here a brief description is given of the state-of-the-art experience in carrying out the countermeasure. Some countermeasures have only been tested on a limited scale.
Key references	These are references for further reading to what is believed to be the key publications on the countermeasure.
Comments	Any further comments not covered by the above are given here.

A few of the terms applied in the database text require definition:

External exposure/dose is defined as exposure/dose to humans from radioactive substances *outside* the body. Conversely, *internal exposure/dose* is the exposure/dose to humans from radioactive substances *inside* the body.

DF (decontamination factor) is defined as the concentration of the original contamination on/in an object relative to what is left after a countermeasure has been carried out. This factor is used to measure the *decontamination efficiency* of countermeasures.

DRF (dose reduction factor) is here defined as the dose rate excluding natural sources before a countermeasure had been carried out relative to that after the countermeasure has been carried out, measured at a reference location in the environment. DRF is a measure of the relative reduction in dose rate obtained by application of one or several countermeasures.

'Surface DRF' (surface dose reduction factor) is defined as the DRF at a distance of 1 m from a surface, regarding the surface as having infinite dimensions, and assuming that no other sources are present. It is a factor that is used to describe the efficiency of countermeasures, which do not decontaminate a surface (i.e., which do not *remove* contamination from the area), but reduce the external dose above it (e.g., by burial of the contamination).

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2 Countermeasure descriptions

The countermeasures for which datasheets are presented in this chapter are listed in the index below, which has been supplemented with short countermeasure descriptions to provide a better overview of the options for treatment of the various types of contaminated urban surface.

INDEX FOR COUNTERMEASURE DATASHEETS	
ROADS, PAVEMENTS AND WALKWAYS	page 16
Road planing: Grinding off a thin contaminated top layer of asphalt surfaces with a road planer (rotating grinding equipment used by contractors). In cases, subsequent re-paving may be necessary.	page 17
Vacuum sweeping roads and walkways: Vacuum sweeping with a type of machine used in many areas of Europe for routine street cleaning. It often has 3 rotating brushes and a vacuuming attachment. The road dust is accumulated in a vessel behind the operator.	page
Firehosing roads and walkways: Hosing with water to remove loosely bound contamination from surfaces of roads or other horizontal pavings. Particularly efficient if applied early after contaminant deposition.	page
Turning flagstones: As the contamination will, after an accident, be distributed on the upper surface of flagstones, turning them will provide a concrete shielding against the radiation from this contamination.	
AREAS OF SOIL INCL. VEGETATION	
Topsoil removal applying lignin coating: Lignin is an inexpensive waste product from for example, the paper manufacturing industry. Applied in wet form on a surface of soil or grass it forms a peelable coating, which can be removed (with a scraper), taking with it a very thin layer of (contaminated) soil particles.	
Topsoil removal by machines (e.g., 'bobcat'): Removal of a thin top layer containing most of the contamination from a soil surface, using a 'bobcat' mini-bulldozer or similar equipment.	
Topsoil removal manually: Manual removal (with a spade) of a thin top layer containing most of the contamination from a soil surface.	
Application of clean sand/soil around dwellings and in frequently occupied areas: Sand or soil from a radiologically clean area can be applied around dwellings, to shield against radiation. Will typically be considered for reduction of residual radiation after removal of a topsoil layer.	
Resurfacing with e.g., asphalt in frequently occupied areas: A layer of asphalt or concrete can be applied in areas adjacent to dwellings, mainly to shield against radiation to people resting or playing outdoors. Can be considered for reduction of residual radiation after removal of a topsoil layer.	
Snow removal e.g., 'bobcat' or 'frontloader': If contaminant deposition occurs to a snow surface, mechanical removal of a snow layer before the first thaw can prevent contamination of underlying (soil or asphalt) surfaces.	
Garden digging: By manually digging the garden, soil layers are mixed, providing some shielding against the radiation from deposited contamination.	
Triple digging: By manually triple digging, the order of three vertical soil lay-	

ers is changed: the thin contaminated top layer is buried in the bottom, with the turf facing down, the bottom layer is placed on top of this, and the intermediate layer (not inverted) is placed at the top. Thereby shielding is achieved with a minimised impact on soil fertility.	
Skim-and-burial ploughing (park areas): The skim-and burial plough ideally skims off a thin top layer, which is placed in the bottom of the vertical soil profile. A deeper soil layer (to about 45 cm) is placed on top of this (this layer is not inverted). Thereby shielding is achieved with a minimised impact on soil fertility.	
Deep ploughing (park areas): By deep ploughing (to about 45 cm) much of the contamination on a soil surface will be buried deep in the vertical profile, so that radiation from the contaminants is substantially reduced.	
Shallow ploughing (park areas): By ordinary ploughing (to about 25 cm) much of the contamination on a soil surface will be buried relatively deep in the vertical profile, so that radiation from the contaminants is reduced.	
Turf harvesting (park areas): A turf harvester is a machine applied in areas such as grass nurseries, for cutting off a thin turf layer of a plane, grassed surface (without rocks). This may be applied to remove much of the contamination from a lawn.	
Lawn mowing: If deposition occurs without precipitation, much of the contamination on a lawn will, in the earliest phase (days to weeks), be present on the grass rather than the soil. Cutting the lawn (and removal of the grass) can therefore, to some extent, prevent soil contamination.	
Pruning or removal of trees and shrubs: If deposition occurs without precipitation, shrubs and trees (particularly if in leaf) may receive and retain very high levels of contamination compared with other vegetation. Their pruning or removal from areas such as gardens may therefore significantly reduce dose to inhabitants.	
WALLS OF DWELLINGS	
High-pressure water hosing of walls: Water hosing with high-pressure nozzles can remove part of the contamination deposited on walls of buildings, especially if applied early after deposition.	
Sandblasting of walls: By sandblasting, using high-pressure air with sand injected, a thin layer of the surface of a wall is removed, taking with it much of the contamination. Wet sandblasting is recommended, as both the efficiency and the control of the generated dust is better.	
NH_4^+ treatment of walls: The ammonium ion has similarities with the caesium ion, and can (on non-specific sorption sites) exchange with caesium contaminating surfaces. A solution of NH_4^+ is sprayed onto the wall at low pressure, ensuring a continuous flow over the wall. The method is generally most efficient soon after contamination has occurred.	
Mechanical abrasion on wooden walls: On painted (impermeable) walls, mechanical abrasion using, for instance, an electric drill with steel wool or sandpaper can be applied to remove the contaminated surface.	
ROOFS OF DWELLINGS	
High-pressure water hosing of roofs: Water hosing with high-pressure nozzle can remove part of the contamination deposited on roofs of buildings, especially if applied early after deposition.	
Roof cleaning by cleaning device: A rotating brush in a 'closed' system, typically mounted on an extendible rod and operated from the ground or from the	

rooftop, can often significantly reduce the contamination level on a roof. An air compressor provides pressure for rotating the brush and tap water at ordinary pressure is needed for rinsing.	
Roof cleaning by pressurised hot water trolley: An oscillating high-pressure water system can be used to remove roof contamination in a 'closed' system mounted on a trolley. This can be operated with a rod or rope from the top of the roof.	
Change of roofs: Naturally, if a roof is changed to an uncontaminated one, the contribution to dose rate from the roof will then be reduced to 0, provided that contamination has not reached deeper into the (wooden) parts of the roof construction.	
INDOOR SURFACES	
Intensive indoor surface cleaning: Dose contributions from indoor contamination may be significant, especially over the first year. Also over longer periods, contamination may be brought into dwellings, for instance attached to the soles of shoes. The countermeasure is self-help advice to carefully clean floor surfaces, particularly carpets thoroughly and with a short time interval after contamination occurs.	

2.1 Countermeasures for reduction of dose from contaminated roads, pavements and walkways

Road planing	
Objective	To reduce external dose rate in the area.
Other Benefits	-
Countermeasure description	Road planing with highways maintenance machinery can remove a thin top layer (ca. 1 cm) of an asphalted road surface in ca. 2 m wide swathes. The grinding is usually accomplished by a rotating drum with grinding picks, but several designs exist. Machines are often equipped with a rotating brush for debris collection to a truck. If not, a device must be added or manual sweeping carried out. As penetration of contaminants into asphalt is negligible, nearly all the contamination can be removed. Similar effect on concrete roads.
Target	Contaminated horizontal asphalt (or concrete) surfaces, such as roads, streets and squares.
Targeted radionuclides	Caesium.
Scale of application	May be considered for contaminated densely populated areas of limited dimensions (urban centres).
Contamination pathway	None
Exposure pathway	External exposure.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. If it is carried out later the averted dose will be significantly less (natural decrease in contamination level by factor of 3 over first year).
Constraints	
• Legal constraints	Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	-
• Environmental constraints	If the road surface is very cambered the grinding depth will not be uniform.
• Communication constraints	Need for public explanation of countermeasure and selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by 80-90 % is achievable.

• Factors influencing effectiveness of procedure (Technical)	Homogeneity of treatment, evenness and condition of roads in relation to grinding depth, removal of loose debris, operator skills.
• Factors influencing effectiveness of procedure (social)	Compliance (owners/workers/public) with appropriate process of application of countermeasure.
Feasibility:	
• Required specific equipment	Large road planer (alternatively, small planers may be used, e.g., mounted on a mini-bulldozer, though these are much more time consuming).
• Required ancillary equipment	Waste transport truck and machinery for constructing repository, depending on waste action scheme.
• Required utilities and infrastructure	Roads to repository, depending on waste action scheme.
• Required consumables	Diesel.
• Required skills	4 operators (skilled workers from a contractor company).
• Required safety precautions	Planer casing protects operators against loosened debris. In heavily contaminated areas protection against inhalation of dust is recommended.
• Other limitations	
Waste:	
• Amount and type	If a 1 cm deep layer is removed, this produces some 15 kg m^{-2} of solid waste. Contamination ca. 100 Bq m^{-3} per Bq m^{-2}.
• Possible transport, treatment and storage routes.	Transport by e.g. trucks or rail, depending on waste action scheme. Simple repositories should be constructed. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential.
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter.
• Factors influencing averted dose	Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Doses received around waste repository, depending on waste action scheme (see also separate Chapter). Influenced by measures taken to protect operators against inhalation, where required.

Intervention Costs:	
• Equipment	Large road planer (ca. 70,000 EURO). Waste transport/ treatment equipment (variable).
• Consumables	Ca. 200 l ha^{-1} of diesel (excl. waste transport) at current cost per litre.
• Operator time	Typically, the procedure is carried out at a rate of 1000 m^2 h^{-1}, and requires 4 workers. In addition, time consumed in waste collection/transport and work at repository.
• Factors influencing costs	Evenness and condition of roads (required grinding depth), planer size, sweeping device, distance to equipment, consumables and repository, operator skills, need for resurfacing (normally not necessary), labour costs. Area size influences cost per unit area.
• Communication costs	Information for operators on correct application of countermeasure.
• Compensation costs	The contractor might demand a premium payment rate for hazardous work.
• Waste cost	Depends on choice of options (see separate Chapter).
• Assumptions	Availability of the required transport roads.
Side-effect evaluation:	
• Ethical considerations	Re-distribution of dose from users of urban spaces to operators and populations around waste facilities. Free informed consent of workers, and consent of owners to access. Liability cover for unforeseen health or property effects. Environmental consequences of waste generation and treatment (chemical and radioactive).
• Environmental impact	Toxicity of waste to be considered at repository.
• Agricultural impact	-
• Social impact	Acceptability and potential for dispute regarding waste disposal sites, and regarding prioritisation of areas to be treated. Maintenance of use of roadways, walkways etc.
• Other side effects, pos. or neg.	The road surface is planed and ready for resurfacing if desired /required. Public reassurance issues.
Practical experience	Tested on a small scale in the CIS, pre-Chernobyl tests in USA.
Key references	Roed et al.: Risø-R-1029; Roed et al.: Risø-R-828; Roed: NKA 1990; Barbier & Chester, PNL, 1980.
Comments	It is generally not recommendable to re-use the granulated asphalt waste mixed in new hot asphalt *on site* (mixing in place), as it should be carefully assessed whether the volumes of new asphalt would dilute the contamination sufficiently.

Vacuum sweeping roads and walkways	
Objective	To reduce external dose in the area.
Other Benefits	-
Countermeasure description	Vacuum sweeper vehicles are used by municipal authorities in many countries for routine street cleaning. These types of devices have also been applied in Kiev to clean streets after the Chernobyl accident. Typically, the ride-on vacuum sweeper is equipped with 3 rotating brushes. Some sweepers apply a water spray, to control resuspension prior to dust removal. The dust is finally removed by a vacuum device and collected in a vessel on the vehicle, typically behind the operator seat. The vessel should be shielded in order to reduce external dose from the sweepings to the driver.
Target	Contaminated horizontal asphalt (or concrete) surfaces, such as roads, walkways and squares.
Targeted radionuclides	Caesium.
Scale of application	Since the process is rapid it can be carried out over large areas, provided that equipment is more or less readily available. Densely populated areas will command a high priority for treatment.
Contamination pathway	None
Exposure pathway	External exposure.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Should be carried out within the first few weeks to have a significant effect.
Constraints	
• Legal constraints	Requirement for radiation protection training of workers.
• Social constraints	-
• Environmental constraints	-
• Communication constraints	-
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by typically 50-70 %, if the action is carried out early.

• Factors influencing effectiveness of procedure (Technical)	Amount of road dust at time of road contamination (great influence). Road surface type (dust particle size). Time of operation (If sweeping is delayed for one week following the contamination, then the reduction in contamination level will be less since fixation to the underlying surface sets in. Also, traffic will remove much of the loosely held contamination, thus reducing achievable DF). Homogeneity of treatment, evenness and condition of roads. To some extent operator skills. Water spraying reducing dust resuspension also increases the effect slightly.
• Factors influencing effectiveness of procedure (social)	-
Feasibility:	
• Required specific equipment	Vacuum sweeping machine.
• Required ancillary equipment	Waste transport truck and machinery for constructing repository, depending on waste action scheme.
• Required utilities and infrastructure	Roads to repository, depending on waste action scheme.
• Required consumables	Petrol, water for spraying (not essential).
• Required skills	1 operator (if the machinery is locally available, the municipal authorities can also supply a skilled operator, who regularly uses the equipment).
• Required safety precautions	In strongly contaminated areas respiratory protection may be recommended if water is not applied for dust control. In strongly contaminated areas the vessel containing the dust must be water-filled. It may even be recommendable to apply a metal shielding between the operator and the waste vessel (possibly also on the waste transport truck).
• Other limitations	
Waste:	
• Amount and type	Typically some 100-200 g m^{-2}. Contamination ca. 5-10,000 Bq m^{-3} per Bq m^{-2}.
• Possible transport, treatment and storage routes.	Transport by e.g. trucks or rail, depending on waste action scheme. Simple repositories should be constructed. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential.
Doses:	

• Averted dose	Highly dependent on environment type. See separate Chapter.
• Factors influencing averted dose	Road gutters must be swept particularly carefully, as contamination may accumulate here (important). Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area. Measures taken to protect operators against inhalation, where required. Shielding against waste in vessels.
• Additional dose	Depends on short-lived radionuclides (time). Without special shielding against waste in vessels, the dose rate to an operator (or waste truck driver) in an area contaminated by 1 MBq m^{-2} of ^{137}Cs may be as high as 50 μSv h^{-1} (compared with ca. 12 μSv d^{-1} typically received by persons living in that area). Doses received around waste repository, depending on waste action scheme (see also separate Chapter). Influenced by measures taken to protect operators against inhalation of contaminated dust, where required.
Intervention Costs:	
• Equipment	Vacuum sweeping machine (ca. 90000 EURO). Waste transport/ treatment equipment (variable).
• Consumables	5-6 litres per hour of petrol. 0.1 m^3 water per hour.
• Operator time	Ca. 3 10^{-4} h per treated m^2. In addition: time for waste collection/transport and work at repository.
• Factors influencing costs	Vacuum sweeper size, distance to equipment, consumables and repository, operator skills. The operation may, in some cases, be considered a part of the routine street cleaning. Labour costs.
• Communication costs	Information for operators on correct application of countermeasure
• Compensation costs	Labour costs may be higher to compensate workers for their exposure to higher risks.
• Waste cost	Depends on choice of options (see separate Chapter).
• Assumptions	Availability of the required transport roads.
Side-effect evaluation:	
• Ethical considerations	Distribution of dose from users of area to operators and populations around waste facilities. Free informed consent of workers and consent of owners for access. Environmental consequences of waste generation.
• Environmental impact	-
• Agricultural impact	-

• Social impact	Maintenance of use of urban roadways, pathways etc. Acceptability and potential for dispute regarding waste disposal sites, and regarding prioritisation of areas to be treated.
• Other side effects, pos. or neg.	The surface is cleaned. Public reassurance issues.
Practical experience	Applied in the CIS after the Chernobyl accident. Small-scale tests conducted in Denmark and USA under varying conditions to examine the influence of e.g., street dust loading.
Key references	Andersson: NKS/EKO-5(96)18; Roed et al.: Risø-R-828; Roed: NKA 1990; Calvert et al., USA EPA, 1984; Andersson & Roed: J. Environ. Rad. 46, 1999.
Comments	

Firehosing roads and walkways	
Objective	To reduce external dose in the area
Other Benefits	-
Countermeasure description	Use of ordinary firehosing equipment for removal of the contamination on road pavings. Water could be taken from a hydrant, if available, or, say from a lake or river.
Target	Contaminated horizontal asphalt (or concrete) surfaces, such as roads, walkways and squares.
Targeted radionuclides	Caesium.
Scale of application	Could be carried out in densely populated areas of limited dimensions, where the equipment is more or less readily available.
Contamination pathway	None
Exposure pathway	External exposure.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Should be carried out within the first few weeks to have a significant effect.
Constraints	
• Legal constraints	Requirement for radiation protection training of workers
• Social constraints	-
• Environmental constraints	Frost (may require heated water).
• Communication constraints	Need for public explanation of countermeasure and selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by typically 50-75 % is normally achievable, if the procedure is carried out early.
• Factors influencing effectiveness of procedure (Technical)	Amount of road dust at time of road contamination (great influence). Road surface type (particle size of dust). Time of operation (the effect is significantly reduced within a week after contamination, due to contaminant fixation. Also, traffic will remove much of the loosely held contamination, thus reducing the effectiveness of the countermeasure). Homogeneity of treatment, evenness and condition of roads. To a limited extent operator skills.

• Factors influencing effectiveness of procedure (social)	Compliance (owners/public/workers) with appropriate process of application of countermeasure.
Feasibility:	
• Required specific equipment	A hosepipe, and a water supply (hydrant or water pump).
• Required ancillary equipment	-
• Required utilities and infrastructure	-
• Required consumables	Water, petrol for pump if required.
• Required skills	The local fire brigade has experience that could be drawn upon, but also military/local inhabitants could perform the operation, given little instruction.
• Required safety precautions	Water-resistant clothing is recommended, particularly for strongly contaminated areas.
• Other limitations	
Waste:	
• Amount and type	Typically some 100-200 g m^{-2} (contamination level ca. 5-10,000 Bq m^{-3} per Bq m^{-2}) of solid waste in some 0.25 m^3 m^{-2} of water.
• Possible transport, treatment and storage routes.	The waste is generally impossible to collect and must be led to the drains with the run-off water. Special care should be taken to avoid accumulating waste by the roadside.
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter.
• Factors influencing averted dose	Road gutters must be hosed carefully, because contamination tends to accumulate here (important). The method should not be considered if roads are not equipped with drains. Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Depends on use of protective clothing, as required.
Intervention Costs:	

• Equipment	Hosepipes etc. are usually available locally. The cost of a hosepipe complete with fittings is ca. 750 EURO. A petrol-driven pump, if required, costs about 6000 EURO.
• Consumables	About 20 m^3 water per hour. If pump is required about 10 litres of petrol per hour.
• Operator time	About 0.01-0.02 h per treated m^2.
• Factors influencing costs	Distance to equipment and consumables, to some extent operator skills, the need for a pump. Labour costs.
• Communication costs	Information for operators on correct application of countermeasure.
• Compensation costs	Labour costs may be higher to compensate workers for their exposure to higher risks.
• Waste cost	-
• Assumptions	Availability of the required roads for transport of equipment, availability of water resources in the area.
Side-effect evaluation:	
• Ethical considerations	Re-distribution of dose from users of urban spaces to operators. Free informed consent of workers and consent of owners. Environmental consequences of waste generation.
• Environmental impact	-
• Agricultural impact	-
• Social impact	Acceptability regarding prioritisation of areas to be treated. Maintenance of use of roadways, walkways etc.
• Other side effects, pos. or neg.	The surface is cleaned. Public reassurance issues.
Practical experience	Small scale tests conducted in Denmark and USA under varying conditions to examine the influence of e.g., street dust loading.
Key references	Andersson: NKS/EKO-5(96)18, 1996; Roed et al.: Risø-R-828; Roed: NKA 1990; Roed & Andersson: J. Environ. Rad. 33, 1996; Andersson & Roed: J. Environ. Rad. 46, 1999; Warming,1984.
Comments	

Turning flagstones	
Objective	To reduce external dose rate in the area.
Other Benefits	-
Countermeasure description	As the contamination will after an accident be attached to the upper surface of flagstones, turning them will provide shielding against radiation from this contamination.
Target	Contaminated flagstones.
Targeted radionuclides	Caesium.
Scale of application	Could be carried out on wide scale.
Contamination pathway	None
Exposure pathway	External exposure.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. As the contamination level on this type of surface typically may decrease by a factor of 2-3 over the first year (depending on amount of traffic), the operation is best carried out early.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Local authority liabilities for evenness of footpaths or damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	Aesthetic consequences of landscape/architecture changes.
• Environmental constraints	-
• Communication constraints	Need for public explanation of countermeasure and selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Reduction of dose rate contribution by ca. 50-80 % achievable.
• Factors influencing effectiveness of procedure (Technical)	Area covered by flagstones ('Surface DRF' on a large surface of flagstones will be greater than that on a small). Thickness and material characteristics of the flagstone (shielding against contamination).

• Factors influencing effectiveness of procedure (social)	Compliance (owners/workers/public) with appropriate process of application of countermeasure
Feasibility:	
• Required specific equipment	Spades or similar tools for excavation. Some flagstones may need replacement, depending on their condition.
• Required ancillary equipment	-
• Required utilities and infrastructure	-
• Required consumables	-
• Required skills	Can be carried out by local inhabitants.
• Required safety precautions	-
• Other limitations	
Waste:	
• Amount and type	None (provided that the flagstones can be turned without breaking).
• Possible transport, treatment and storage routes.	-
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter.
• Factors influencing averted dose	Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area.
Intervention Costs:	
• Equipment	Spade (ca. 15-20 EURO). Possibly some new flagstones, according to need.
• Consumables	- sand/mortar/cement
• Operator time	Ca. 10-20 minutes per treated m^2.
• Factors influencing costs	Operator skills, labour costs.
• Communication costs	

• Compensation costs	Labour costs may be higher to compensate workers for their exposure to unusual risks.
• Waste cost	Generally none expected.
• Assumptions	-
Side-effect evaluation:	
• Ethical considerations	Potential for self-help Free informed consent of workers and consent of owners. Liability cover for unforeseen health consequences e.g. stumbling over uneven surfaces.
• Environmental impact	-
• Agricultural impact	-
• Social impact	Acceptability and potential for dispute regarding prioritisation of areas to be treated. Maintenance of use of roadways, walkways, etc.
• Other side effects, pos. or neg.	Inversion of the flagstones may present a visually less attractive surface. Public reassurance issues.
Practical experience	Only very small experiments have been made, but calculation can demonstrate the potential effectiveness.
Key references	Roed et al.: Risø-R-828; Roed: NKA 1990; Hubert et al.: EUR 16530.
Comments	

2.2 Countermeasures for reduction of dose from contaminated areas of soil including vegetation

Topsoil removal applying lignin coating	
Objective	To reduce the external dose rate in the area.
Other Benefits	Reduction of internal dose from consumption of kitchen garden products, if produced.
Countermeasure description	Gamma spectrometric analysis of soil core sample sections shows how deep a layer of soil should optimally be removed from a garden or park area to maximise dose reduction with minimal impact on soil fertility. In some cases (particularly with dry deposition), this layer can be very thin (ca. 1 cm). A thin layer of lignin (non-toxic waste product from paper production) can be sprayed onto the ground. This will mix with soil particles in a thin top layer (according to water dilution and environmental moisture) and 'embed' the topsoil particles in a thin layer facilitating removal by scraping.
Target	Grassed areas and other areas of soil, which have not been tilled since contamination.
Targeted radionuclides	Caesium (plus other radionuclides if edible products are grown).
Scale of application	Can be carried out on a large scale where equipment/lignin is available.
Contamination pathway	None (possibly root-uptake in kitchen gardens).
Exposure pathway	Mainly external exposure from contaminated land. Possibly also dose from consumption of contaminated kitchen garden products.
Time of application	Shortly after a dry deposition (since penetration is slow, a delay of some weeks could be tolerated). Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered.
Constraints	
• Legal constraints	Local authority liabilities for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	Acceptability of removal of topsoil and plants. Aesthetic consequences of landscape/amenity changes.
• Environmental constraints	Soil texture (rocks) and frost may be restrictions. Soil must not be covered by snow. If the soil moisture is high, the lignin will not dry sufficiently to form a layer with sufficient strength to facilitate the scraping. To facilitate layer formation, any grass/ vegetation should be cut as short as possible prior to use of this method.

• Communication constraints	Need for public explanation of countermeasure and dialogue on selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by ca. 65-85 % if optimised according to contaminant distribution in soil.
• Factors influencing effectiveness of procedure (Technical)	It can be very difficult to control the downward migration of the lignin. The method has higher effect on bare soil than on grass cover. Optimisation of thickness of removed soil layer (operator skills). Evenness of ground surface. Vertical Cs penetration (should not be deeper than about 1 cm). Uniformity of vertical distribution of Cs. Soil texture and moisture (e.g., friable soils may be difficult to remove completely). Elapsed time (downward migration of Cs in soil over long periods).
• Factors influencing effectiveness of procedure (social)	Compliance (owners/workers/public) with appropriate process of application of countermeasure.
Feasibility:	
• Required specific equipment	Water spray truck with large tank and spraying device, (manual) scrapers for soil/lignin layer removal.
• Required ancillary equipment	Waste transport truck (or other means of transport) to repository and machinery for constructing repository, depending on waste action scheme.
• Required utilities and infrastructure	Roads to repository, depending on waste action scheme. Water.
• Required consumables	Petrol, lignin.
• Required skills	Local contractors and agricultural/ municipal workers who have some relevant skills/ routine (lignin is in some countries applied in this way on dirt roads for dust control). Care must be taken to scrape (or peel) off only the coherent contaminated layer.
• Required safety precautions	Respiratory protection and protective clothes recommended.
• Other limitations	
Waste:	
• Amount and type	If a 1 cm top-layer is removed, this produces about 15 kg m^{-2} of waste. Contamination ca. 100 Bq m^{-3} per Bq m^{-2}.

• Possible transport, treatment and storage routes.	Transport by e.g. trucks or rail, depending on waste action scheme. Simple repositories should be constructed. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential. The amount of waste will be less than that produced by most other 'soil removal' procedures.
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter.
• Factors influencing averted dose	Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area. If edible crops are grown the method can reduce their contaminant content corresponding to DF.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Influenced by measures taken to protect operators against e.g., inhalation, and contamination of skin/ clothes. Doses received around waste repository, depending on waste action scheme (see also separate Chapter).
Intervention Costs:	
• Equipment	Water spray truck with large tank and spraying device (ca. 120,000 EURO), manual scrapers for layer removal (ca. 20 EURO each). Waste transport/ treatment equipment (variable).
• Consumables	Lignin diluted with water (typically ca. 0.05-0.10 EURO m^{-2}). Petrol for lignin/water mixture / waste transport (depending on distance), at current cost per litre.
• Operator time	Application of lignin/water mixture (ca. 10-20 h per ha). Removal by manual scraper (estimated to ca. 100-200 h per ha), incl. loading to waste transport truck, but excl. waste transport and work at repository.
• Factors influencing costs	Mainly labour skills, layer depth. Distance to equipment, consumables and repository, labour costs. Area size influences cost per m^2.
• Communication costs	Information for operators on correct application of countermeasure. Informing the public on rationale for countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	Public/owner compensation for possible damage to property/amenity. Payment of premium rates for labour to compensate workers for their exposure to higher risks.
• Waste cost	Depends on choice of options (see separate Chapter).

• Assumptions	Availability of the required roads.
Side-effect evaluation:	
• Ethical considerations	Re-distribution of dose from users of urban spaces to operators and populations around waste facilities. Free informed consent of workers and consent of owners. Environmental consequences of waste generation and disposal.
• Environmental impact	Possible adverse impact on bio-diversity. Soil erosion risk.
• Agricultural impact	Possible adverse impact on soil fertility (though minimised). Requires replanting (and possibly fertilisation).
• Social impact	Maintenance of use of urban spaces, kitchen gardens and produce. Acceptability and potential for dispute regarding waste disposal sites, and conflict regarding selection of areas for treatment.
• Other side effects, pos. or neg.	Adverse aesthetical effect of treatment. Public reassurance issues.
Practical experience	Tested on a small scale (only few m^2) in Denmark. Full-scale tests in e.g., USA and Sweden only had the purpose of dust suppression.
Key references	Andersson & Roed: J. Environ. Rad. 22, 1994; Tawil & Bold: Report PNL-4903, Pacific Northwest Lab., 1983.
Comments	

Topsoil removal by machines (e.g., 'Bobcat')	
Objective	To reduce the external dose rate in the area.
Other Benefits	Reduction of ingestion dose from consumption of kitchen garden products, if produced.
Countermeasure description	Almost invariably, caesium fallout deposited on soil remains in the topmost few centimetres for many years -this is certainly the case on clays and brown earths. Gamma spectrometric analysis of soil core sample sections shows how deep a layer should be removed to maximise dose reduction with minimal impact on soil fertility. The removal may be carried out by 'bobcat' mini-bulldozers (easy to manoeuvre in small areas) or similar available equipment.
Target	Grassed areas and other areas of soil, which have not been tilled since contamination. Also tilled areas may be treated, but the waste volume will be much greater, since it will be necessary to remove a thicker layer.
Targeted radionuclides	Caesium (plus other radionuclides if edible products are grown).
Scale of application	Can be carried out on a large scaleon a large scale where equipment is or can be made available.
Contamination pathway	None (possibly root-uptake in kitchen gardens).
Exposure pathway	Mainly external exposure from contaminated land. Possibly also dose from consumption of contaminated kitchen garden products.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose. As the procedure would often have nearly same effect on dose rate after one week as after two years, one set of equipment can treat a large area.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Local authority liabilities for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	Acceptability of removal of topsoil with associated removal of flora and fauna. Aesthetic consequences of landscape/amenity changes.

• Environmental constraints	Soil texture (big rocks) and in some cases frost may be restrictions. Soil should not be covered by snow. Under extreme conditions also area slope (largely depending on operator skills).
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by ca. 90-97 % if optimised according to contaminant distribution in soil.
• Factors influencing effectiveness of procedure (Technical)	Optimisation of thickness of removed soil layer (operator skills). Evenness of ground surface. Uniformity of vertical distribution of Cs. Soil texture (e.g., friable soil layers will be more difficult to remove completely). Time (downward migration of Cs in soil over long periods).
• Factors influencing effectiveness of procedure (social)	Compliance (owners/public/workers) with appropriate process of application of countermeasure.
Feasibility:	
• Required specific equipment	'Bobcat' mini-bulldozer or bulldozer.
• Required ancillary equipment	Waste transport truck (or other means of transport) to repository and machinery for constructing repository, depending on waste action scheme.
• Required utilities and infrastructure	Roads to repository, depending on waste action scheme.
• Required consumables	Petrol.
• Required skills	Local contractors or municipal workers who have the required skills/ routine, and could, if necessary, instruct others within a day. Care must be taken to remove soil to the optimal depth, and not 'plough' the contamination into the 'cleaned' surface.
• Required safety precautions	Early after accident and under very dusty conditions respiratory protection and protective clothes may be recommended.
• Other limitations	
Waste:	
• Amount and type	If 5 cm topsoil is removed, about 70 kg m^{-2} of waste will accrue. Contamination ca. 20 Bq m^{-3} per Bq m^{-2}.

• Possible transport, treatment and storage routes.	Transport by e.g. trucks or rail, depending on waste action scheme. Simple repositories should be constructed. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential.
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter
• Factors influencing averted dose	Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area. If edible crops are grown the method can reduce their contaminant content corresponding to DF.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Influenced by measures taken to protect operators against e.g., inhalation, and contamination of skin/ clothes, where required. Doses received around waste repository, depending on waste action scheme (see also separate Chapter).
Intervention Costs:	
• Equipment	'Bobcat' (ca. 40,000 EURO) or larger bulldozer (ca. 90,000 EURO). Waste transport/ treatment equipment (variable).
• Consumables	Ca. 40 l ha^{-1} of petrol (excl. waste transport) at current cost per litre.
• Operator time	Typically some 50-100 h per ha, incl. loading to waste transport truck, but excl. waste transport and work at repository.
• Factors influencing costs	Mainly labour skills, layer depth, vegetation to be removed, and machinery type. Distance to equipment, consumables and repository, labour costs. Area size influences cost per m^2.
• Communication costs	Information for operators on correct application of countermeasure. Provision of information for public on rationale for countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	Public/owner compensation for possible damage to property/amenity. Labour costs may be higher to compensate workers for exposure to radiation.
• Waste cost	Depends on choice of options (see separate Chapter).
• Assumptions	Availability of the required roads.
Side-effect evaluation:	

• Ethical considerations	Re-distribution of dose from users of urban spaces to operators and populations around waste facilities. Free informed consent of workers and consent of owners. Compensation for property/amenity damage/change. Environmental consequences of waste generation.
• Environmental impact	Possible (partial) loss of bio-diversity. Soil erosion risk.
• Agricultural impact	Possible (partial) loss of soil fertility. May in some soils remove the entire fertile layer. Requires fertilisation / replanting.
• Social impact	Maintenance of use of urban spaces. Acceptability and potential for dispute regarding waste disposal sites, and conflict regarding selection of areas for disposal.
• Other side effects, pos. or neg.	Adverse aesthetical effect of treatment. Public reassurance issues.
Practical experience	Tested on semi-large scale (ca. 2000 m^2) on several occasions in the CIS.
Key references	Roed et al.: Risø-R-1029; Andersson: NKS/EKO-5(96)18; Roed et al.: Risø-R-828; Fogh et al.: Health Physics, 1999; Vovk et al.: Sci. Tot. Env., 1993; Andersson & Roed: J. Environ. Rad. 46, 1999.
Comments	

Topsoil removal manually	
Objective	To reduce the external dose rate in the area.
Other Benefits	Reduction of ingestion dose from consumption of kitchen garden products, if produced.
Countermeasure description	Almost invariably, caesium fallout deposited on soil remains in the topmost few centimetres for many years -this is certainly the case on clays and brown earths. Gamma spectrometric analysis of soil core sample sections shows how deep a layer should be removed to maximise dose reduction with minimal impact on soil fertility. The removal may be carried out manually with a spade.
Target	Grassed areas and other areas of soil, which have not been tilled since contamination. Also tilled areas may be treated, but the waste volume will be much greater, since it will be necessary to remove a thicker layer.
Targeted radionuclides	Caesium (plus other radionuclides if edible products are grown).
Scale of application	Can be carried out on a large scale
Contamination pathway	None (possibly root-uptake in kitchen gardens).
Exposure pathway	Mainly external exposure from contaminated land. Possibly also dose from consumption of contaminated kitchen garden products.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose. As the procedure would often have nearly same effect on dose rate after one week as after two years, it could be accomplished over a long period.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Liabilities for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	Acceptability of removal of topsoil with associated removal of flora and fauna. Aesthetic consequences of landscape/amenity changes.
• Environmental constraints	Soil texture (big rocks), snow cover, and in some cases frost may be restrictions/ impediments.

• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment if undertaken collectively. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by ca. 90-97 % if optimised according to contaminant distribution in soil.
• Factors influencing effectiveness of procedure (Technical)	Optimisation of thickness of removed soil layer. Evenness of ground surface. Uniformity of vertical distribution of Cs. Soil texture (e.g., dry crumbling soil layers will be more difficult to remove completely). Time (downward migration of Cs in soil).
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure. Extent of take-up at local/household level as self help measure.
Feasibility:	
• Required specific equipment	Spades.
• Required ancillary equipment	Waste transport truck (or other means of transport) to repository and machinery for constructing repository, depending on waste action scheme.
• Required utilities and infrastructure	Roads to repository, depending on waste action scheme.
• Required consumables	Petrol for waste transport.
• Required skills	Local inhabitants given little instruction. Care must be taken to remove soil to the optimal depth.
• Required safety precautions	Early after accident and under very dusty conditions respiratory protection and protective clothes may be recommended.
• Other limitations	
Waste:	
• Amount and type	If 5 cm topsoil is removed, this produces a waste corresponding to some 70 kg m^{-2}. Contamination ca. 20 Bq m^{-3} per Bq m^{-2}.
• Possible transport, treatment and storage routes.	Transport by e.g. trucks or rail, depending on waste action scheme. Simple repositories should be constructed. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential.
Doses:	

• Averted dose	Highly dependent on environment type. See separate Chapter.
• Factors influencing averted dose	Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area. If edible crops are grown the method can reduce their contaminant content corresponding to DF.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Doses received around waste repository, depending on waste action scheme (see also separate Chapter). Depends on measures taken to protect operators against e.g., inhalation, and contamination of skin/ clothes, where required.
Intervention Costs:	
• Equipment	Spade (ca. 15-20 EURO). Waste transport/ treatment equipment (variable).
• Consumables	Petrol for waste transport (depends on distance and means).
• Operator time	Typically some 0.1 h per m^2, incl. loading to waste transport truck, but excl. waste transport and work at repository.
• Factors influencing costs	Layer depth. Vegetation to be removed. Distance to repository. Individual work rates. Labour costs. Area size influences cost per m^2.
• Communication costs	Information for operators on correct application of countermeasure. Provision of information for public on rationale for countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	Labour costs may be higher to compensate workers for their exposure to higher risks.
• Waste cost	Depends on choice of options (see separate Chapter).
• Assumptions	Availability of the required roads for waste transport.
Side-effect evaluation:	
• Ethical considerations	Re-distribution of dose from users of urban spaces to operators and populations around waste facilities. Potential for self-help. Free informed consent of workers and consent of owners. Compensation for property/amenity damage/change. Waste generation and environmental risk.
• Environmental impact	Possible (partial) loss of bio-diversity. Soil erosion risk.

• Agricultural impact	Possible (partial) loss of soil fertility. May in some soils remove the entire fertile layer. Requires fertilisation / replanting.
• Social impact	Maintenance of use of urban spaces. Maintenance of production from kitchen gardens. Acceptability and potential for dispute regarding waste disposal sites and conflict regarding selection of areas for treatment.
• Other side effects, pos. or neg.	Adverse aesthetical effect of treatment. Public reassurance issues.
Practical experience	Tested on semi-large scale (ca. 400 m^2) on several occasions in the CIS. Carried out on a large scale scale by the Russian authorities after the Chernobyl accident, but not optimised with respect to contaminant distribution, and not carried out consistently over a large area.
Key references	Roed et al.: Risø-R-870; Fogh et al.: Health Physics, 1999.
Comments	

Application of clean sand/soil around dwellings and in frequently occupied areas	
Objective	To reduce the external dose rate in the area.
Other Benefits	Reduction of ingestion dose from consumption of kitchen garden products, if produced.
Countermeasure description	Radiologically 'clean' sand or soil (either excavated from deep soil layers, to which contaminants have not penetrated, or from uncontaminated sources) can be applied around dwellings, and in other open areas, where people spend much time (e.g., playgrounds), to shield against radiation in the ground. This option may typically be applied to reduce the dose rate from residual contamination in a soil surface after removal of a topsoil layer.
Target	Soil (e.g., grassed) areas and other open areas around dwellings.
Targeted radionuclides	Caesium (plus other radionuclides if edible products are grown).
Scale of application	Can be carried out on a large scale around dwellings, if clean cover material can be found.
Contamination pathway	None (possibly root-uptake in kitchen gardens).
Exposure pathway	Mainly external exposure from contaminated land. Possibly also dose from consumption of contaminated kitchen garden products.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose. As the procedure would often have nearly same effect on dose rate after one week as after two years it could be accomplished over a long period.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Liabilities for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	Acceptability of smothering of flora and fauna. Aesthetic consequences of landscape/amenity changes.
• Environmental constraints	Sand/soil can not be supplied from deep layers during periods of frost. The landscape should not be snow-covered.
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	

• Countermeasure effectiveness	Reduction of dose rate contribution by optimally some 75-85 % by application of 10 cm soil over a large area (>100 m^2).
• Factors influencing effectiveness of procedure (Technical)	Layer thickness. Size of treated area (large areas will have higher 'surface' DRF). Traces of contamination in 'uncontaminated' soil/sand. Evenness of ground surface.
• Factors influencing effectiveness of procedure (social)	Correctness of application of countermeasureExtent of take-up at local/household level as self help measure
Feasibility:	
• Required specific equipment	Recommended equipment for digging and applying soil/sand: 'Bobcat' mini-bulldozer. The procedure could also be carried out by spades, though much more labour intensive.
• Required ancillary equipment	Trucks for transport of uncontaminated soil/sand.
• Required utilities and infrastructure	Roads for transport of clean sand/soil.
• Required consumables	Petrol, clean soil/sand.
• Required skills	Local contractors or municipal workers who have the required skills/ routine, and could, if necessary, instruct others within a day. Care must be taken to distribute the sand/soil layer evenly.
• Required safety precautions	-
• Other limitations	
Waste:	
• Amount and type	None
• Possible transport, treatment and storage routes.	-
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter

• Factors influencing averted dose	Population density and behaviour pattern. Age of persons exposed. Consistency (both vertically and horizontally) in carrying out the procedure over a large area (without treatment, about one-third of the dose rate from an infinitely large open soil area will in the early phase be expected to come from contamination more than 16 m away. However, the shielding provided by e.g., buildings in an urban/industrial area will greatly limit dose rate contributions from afar).
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area.
Intervention Costs:	
• Equipment	'Bobcat' (ca. 40,000 EURO) or larger bulldozer (ca. 90,000 EURO). Soil/sand transport truck (ca. 70,000 EURO, variable).
• Consumables	Ca. 60 l ha^{-1} of petrol plus petrol for transport of uncontaminated soil, at current cost per litre.
• Operator time	Typically some 80-160 h per ha, incl. digging up clean sand/soil, but excl. transport of sand/soil to site (variable).
• Factors influencing costs	Layer thickness, operator skills, sand/soil type and conditions (e.g., moisture, season), vegetation, topography. Area size influences cost per m^2. Distance to clean sand/soil supply and to equipment and consumables. Labour costs.
• Communication costs	Provision of information for public on rationale for countermeasure operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	Labour costs may be higher to compensate workers for their exposure to higher risks.
• Waste cost	-
• Assumptions	Availability of the required roads for 'clean' sand/soil transport.
Side-effect evaluation:	
• Ethical considerations	Potential for self help (if clean cover materials supplied). Free informed consent of workers. Compensation for property/amenity damage/change.
• Environmental impact	Soil erosion risk (of applied clean soil/sand).
• Agricultural impact	Positive or negative effect on fertility, depending on quality of the applied soil or sand layer. May require fertilisation / replanting.
• Social impact	Maintenance of use of urban spaces. Acceptability and potential for dispute regarding basis of selection of areas to be treated.

• Other side effects, pos. or neg.	Adverse aesthetical effect of treatment. Severely complicates subsequent *removal* of the contamination. Public reassurance issues.
Practical experience	The method has been tested intensively in the CIS.
Key references	Roed et al.: Risø-R-1029; Roed et al.: Risø-R-870; Fogh et al.: Health Physics, 1999.
Comments	

Resurfacing with e.g., asphalt in frequently occupied areas	
Objective	To reduce the external dose rate in the area.
Other Benefits	
Countermeasure description	A layer of asphalt (or alternatively, e.g., concrete or paving stones) can be applied in frequently occupied areas, e.g., adjacent to dwellings, mainly to shield against radiation to persons (resting/playing) outdoors. Will often be considered for reduction of residual radiation after removal of a topsoil layer. Generally, the procedure would be to apply a layer of stabilising gravel, then asphalt (by shovels and other hand-tools) and finally apply a roller to consolidate.
Target	Soil areas and other open areas of limited dimensions (typically around urban/industrial buildings), where people generally spend much time when outdoors.
Targeted radionuclides	Caesium.
Scale of application	Can be carried out on a large scale around dwellings, if asphalt (or, alternatively, e.g., paving stones) can be supplied.
Contamination pathway	None.
Exposure pathway	External exposure from contaminated land.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Even after a decade a significant fraction of the 70 y dose can be averted. As the procedure would often have nearly same effect on dose rate after one week as after two years it could be accomplished over a long period.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Liabilities for possible damage to property. Ownership and access to property Requirement for radiation protection training of workers
• Social constraints	Acceptability of smothering flora and fauna/change from soil to e.g. tarmac surface. Aesthetic consequences of landscape/amenity changes.
• Environmental constraints	Generally requires temperatures above 5 °C. Otherwise asphalt will cool to rapidly and the consolidation will be inadequate. Slope of terrain (max. ca. 30 °).

• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Reduction of dose rate contribution by typically some 50-75 % by application of 5-6 cm asphalt over a relatively large area (>20 m^2).
• Factors influencing effectiveness of procedure (Technical)	Layer thickness (typically 5-10 cm). Size of treated area (large areas will have higher 'surface' DRF). Density (for asphalt - dependent on type of pebbles - typically ca. 1.6 g cm^{-3}, and max. ca. 2 g cm^{-3}). Traces of contamination in the cover material. Evenness of ground surface.
• Factors influencing effectiveness of procedure (social)	Compliance (owners/workers/public) with appropriate process of application of countermeasure.
Feasibility:	
• Required specific equipment	Small asphalt roller, shovels, special 'rakes' for planing gravel / asphalt layers.
• Required ancillary equipment	Trucks for transport of roller, asphalt and stabilising gravel.
• Required utilities and infrastructure	Roads for transport of asphalt (or concrete).
• Required consumables	Asphalt, stabilising gravel, petrol.
• Required skills	Professional road workers who have the required skills/ routine.
• Required safety precautions	The usual precautions for asphalt workers (helmets, gloves, safety shoes).
• Other limitations	
Waste:	
• Amount and type	None
• Possible transport, treatment and storage routes.	-
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter

• Factors influencing averted dose	Population density and behaviour pattern. Age of persons exposed. Size of treated area in relation to type of environment (without treatment, about one-third of the dose rate from an infinitely large open soil area will in the early phase be expected to come from contamination more than 16 m away. However, the shielding provided by e.g., buildings in an urban/industrial area will greatly limit dose rate contributions from afar).
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area.
Intervention Costs:	
• Equipment	Small roller (ca. 30-40,000 EURO), shovels (15-20 EURO a piece), special 'rakes' for planing (ca. 100 EURO). Asphalt/roller transport trucks (ca. 70,000 EURO each, variable).
• Consumables	Petrol for roller and (mainly) transport of machinery and asphalt/gravel depending on distance, at current cost per litre. Asphalt and stabilising gravel (ca. 5-7 EURO m^{-2}).
• Operator time	Asphalting of 50 m^2 (application of gravel and asphalt and compression) typically takes 4 persons some 3-4 hours. In addition variable transport costs.
• Factors influencing costs	Layer thickness, individual work rates, asphalt type, need for draining/sewerage, vegetation that may need to removed prior to asphalting. Distance to asphalt factory/machines and to consumables. Labour costs. Area size influences cost per m^2.
• Communication costs	Provision of information for public on rationale for countermeasure. operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	Public/owner compensation for possible damage to property/amenity. Labour costs may be higher to compensate workers for their exposure to higher risks.
• Waste cost	-
• Assumptions	Asphalt factory (or alternatively e.g., concrete mixer) available in the area. Availability of the required roads for transport.
Side-effect evaluation:	
• Ethical considerations	Free informed consent of workers and consent of owners. Compensation for property/amenity damage/change.
• Environmental impact	Total loss of biodiversity in the treated area.

• Agricultural impact	Total loss of fertility in the treated area.
• Social impact	Maintenance of use of urban spaces, although changes of use are likely. Acceptability and potential for conflict regarding basis of selection of areas to be treated.
• Other side effects, pos. or neg.	Adverse aesthetical effect of treatment. Complicates subsequent *removal* of the underlying contamination. Public reassurance issues.
Practical experience	The method has been widely applied in the CIS after the Chernobyl accident.
Key references	Gjørup et al.: Risø-R-462, 1982; Hedemann Jensen, et al: Risø-R-356, 1977.
Comments	The asphalting process may, e.g., also be carried out by application of a thick layer of gravel, followed by spraying on a thin sealing asphalt emulsion layer, and on the top a thin layer of gravel.

Snow removal	
Objective	To reduce the external dose rate in the area.
Other Benefits	Reduction of ingestion dose from consumption of kitchen garden products, if produced.
Countermeasure description	If contamination occurs in open areas covered by a thick layer of snow, the removal of the snow layer (or e.g., the upper 5-10 cm snow, depending on snowfall subsequent to contamination) before the first thaw will prevent the contaminants from reaching the underlying ground surface. Generally, soil areas will be most important to treat, but the method could also be applied on paved surfaces. The removal may be carried out by 'Bobcat' mini-bulldozers (easy to manoeuvre in small areas) or similar available equipment. Alternatively, and much more slowly, by spades or manual scrapers.
Target	Open areas (particularly grassed areas and other areas of soil).
Targeted radionuclides	Caesium (plus other radionuclides if edible products are grown).
Scale of application	Can be carried out on a large scale where equipment is or can be made available before first thaw.
Contamination pathway	None (possibly root-uptake in kitchen gardens).
Exposure pathway	Mainly external exposure from contaminated land. Possibly also dose from consumption of contaminated kitchen garden products.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Must be carried out before the first thaw following the contamination.
Constraints	
• Legal constraints	Ownership and access to property. Requirement for radiation protection training of workers
• Social constraints	-
• Environmental constraints	Under extreme conditions also area slope (largely depending on operator skills). For instance trees and shrubs may be obstacles.
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by ca. 90-97 %.

• Factors influencing effectiveness of procedure (Technical)	To obtain a good effect, the snow layer must be sufficiently thick to allow complete removal of the snow surface. If e.g., human activity has compressed the snow, complete removal will be more difficult. Snowdrift may reduce effect.
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure. Extent of take-up at local/household level as self help measure.
Feasibility:	
• Required specific equipment	'Bobcat' mini-bulldozer or similar equipment (e.g., tractor with scraper).
• Required ancillary equipment	Transport truck with waste container (or other means of transport) to disposal site.
• Required utilities and infrastructure	Roads to disposal site.
• Required consumables	Petrol.
• Required skills	Local contractors or municipal workers who have the required skills/ routine, and could, if necessary, instruct others within a day. The snow removal may also be carried out manually by local inhabitants.
• Required safety precautions	Water proof clothing/ boots/ gloves. In case of dry frost / storm weather respiratory protection when carrying out the procedure early after contamination.
• Other limitations	
Waste:	
• Amount and type	Depends on snow layer thickness. If 5 cm snow is removed, this produces a waste corresponding to some 50 kg m^{-2}. Contamination ca. 20 Bq m^{-3} per Bq m^{-2}.
• Possible transport, treatment and storage routes.	Transport by e.g. trucks or rail, depending on waste action scheme. May be disposed of in the sea. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and disposal route are essential.
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter
• Factors influencing averted dose	Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area. If edible crops are grown the method can reduce their contaminant content corresponding to DF.

• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Doses received by waste disposal, depending on waste action scheme (see also separate Chapter). Depends on use of waterproof clothing, where required.
Intervention Costs:	
• Equipment	'Bobcat' (ca. 40,000 EURO) or tractor with scraper (ca. 50,000 EURO). Waste transport/ treatment equipment (variable).
• Consumables	Ca. 40 l ha^{-1} of petrol (excl. waste transport) at current cost per litre.
• Operator time	Typically some 20-40 h per ha, incl. loading to waste transport truck, but excl. waste transport and work at disposal site.
• Factors influencing costs	Mainly labour skills, snow layer thickness, vegetation and other obstacles, and machinery type. Waste disposal scheme. Distance to equipment, consumables and disposal site. Labour costs. Area size influences cost per m^2.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	-
• Waste cost	Depends on choice of options (see separate Chapter).
• Assumptions	Availability of the required transport roads.
Side-effect evaluation:	
• Ethical considerations	Re-distribution of dose from users of land/consumers of produce from land to operators. Potential for self help. Free informed consent and compensation of workers.
• Environmental impact	-
• Agricultural impact	-
• Social impact	Allows continued use of urban spaces. Acceptability and potential for dispute regarding waste disposal sites, and conflict regarding selection of areas for treatment
• Other side effects, pos. or neg.	Limited adverse aesthetical effect, due to the use of relatively heavy machinery in garden areas. Public reassurance issues.
Practical experience	Successfully tested on relatively small scale in Norway.

Key references	Andersson: NKS/EKO-5(96)18; Qvenild & Tveten: ISBN 82-7017-067-4, 1984; Andersson & Roed: J. Environ. Rad. 46, 1999.
Comments	

Garden digging	
Objective	To reduce the external dose rate in the area.
Other Benefits	Possibly some reduction of ingestion dose from consumption of kitchen garden products, if produced.
Countermeasure description	Without intervention, Almost invariably, caesium fallout deposited on soil remains in the topmost few centimetres for many years -this is certainly the case on clays and brown earths. Therefore, if the top layers of the soil are dug to a depth of ca. 30 cm and it is attempted to bring the turf to the bottom of this vertical profile, a significant shielding against radiation from the contaminants is provided.
Target	Grassed areas and other areas of soil, which have not been tilled since contamination.
Targeted radionuclides	Caesium (plus other radionuclides if edible products are grown).
Scale of application	Can be carried out on a large scale in garden areas by house owners.
Contamination pathway	None (possibly root-uptake in kitchen gardens).
Exposure pathway	Mainly external exposure from contaminated land. Possibly also dose from consumption of contaminated kitchen garden products.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose. As the procedure would often have nearly same effect on dose rate after one week as after two years it could be accomplished over a long period. Can not be carried out during periods of frost.
Constraints	
• Legal constraints	Liabilities for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers
• Social constraints	Acceptability of smothering flora and fauna and destruction of garden planting
• Environmental constraints	Soil texture (big rocks) and frost may be restrictions.
• Communication constraints	Need for public explanation of countermeasure
Effectiveness:	

• Countermeasure effectiveness	Reduction of dose rate contribution by typically ca. 50-75 %. If edible crops are grown the method may reduce consumption dose, depending on crop root system.
• Factors influencing effectiveness of procedure (Technical)	Size of treated area (large areas will have higher 'surface' DRF). Soil type and conditions (loose soil will be more difficult to treat with the optimal effect). Uniformity of vertical distribution of Cs. Time (downward Cs migration in soil). Contaminant resuspension could possibly have an impact on effectiveness if the method is carried out very early.
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure. Extent of take-up at local/household level as self help measure
Feasibility:	
• Required specific equipment	Spades.
• Required ancillary equipment	-
• Required utilities and infrastructure	-
• Required consumables	-
• Required skills	Can be carried out by local inhabitants given only little instruction.
• Required safety precautions	Particularly, early after accident and under very dusty conditions respiratory protection and protective clothes may be recommended.
• Other limitations	Contaminants will be brought closer to the groundwater level. The method involves manual work of which some people will not be capable..
Waste:	
• Amount and type	None
• Possible transport, treatment and storage routes.	-
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter

• Factors influencing averted dose	Consistency in carrying out the procedure over a large area (without treatment, about one-third of the dose rate from an infinitely large open soil area will in the early phase be expected to come from contamination more than 16 m away. However, the shielding provided by e.g., buildings in an urban/industrial area will greatly limit dose rate contributions from afar). Population density and behaviour pattern. Age of persons exposed. If edible crops are grown the method may reduce consumption dose, depending on crop root system.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Influenced by measures taken to protect operators against inhalation of contaminants and contamination of skin/clothes, where required.
Intervention Costs:	
• Equipment	Spade (ca. 15-20 EURO).
• Consumables	-
• Operator time	Ca. 10-15 minutes per m^2.
• Factors influencing costs	Individual work rates, Soil type and conditions (e.g., moisture, season), vegetation, topography, labour costs.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators/householders on correct application of countermeasure.
• Compensation costs	-
• Waste cost	None.
• Assumptions	
Side-effect evaluation:	
• Ethical considerations	Potential for self-help Possible (limited) redistribution of dose via groundwater. Free informed consent and compensation of workers. Compensation for property/amenity damage/change.
• Environmental impact	The procedure brings contamination closer to the groundwater. Cs will however normally be very strongly bound. Possible (partial) loss of biodiversity. Soil erosion risk.
• Agricultural impact	Possible (partial) loss of soil fertility. May require fertilisation / replanting.

• Social impact	Maintenance of use of urban areas, but restrictions on future use (e.g. banning digging to this depth (30cm) on allotments) and hence soil fertility/methods of gardening. Destruction of gardens or amenity areas. Potential for competition/dispute regarding different rates of application if these are the responsibility/choice of individuals.
• Other side effects, pos. or neg.	Adverse aesthetical effect of treatment. Severely complicates subsequent *removal* of the contamination. Public reassurance issues.
Practical experience	The method has been tested on a small scale in Europe.
Key references	Roed et al.: Risø-R-828; Roed: NKA 1990.
Comments	Other methods, such as triple digging, are more efficient in reducing dose rate.

Triple digging	
Objective	To reduce the external dose rate in the area (with minimised fertility loss).
Other Benefits	Reduction of ingestion dose from consumption of kitchen garden products, if produced.
Countermeasure description	Almost invariably, caesium fallout deposited on soil remains in the topmost few centimetres for many years -this is certainly the case on clays and brown earths. The order of three vertical layers of soil is changed manually (by spade). The thin top layer (ca. 5 cm -optimised according to contamination depth) carrying nearly all contamination is buried in the bottom, with the vegetation (turf) facing down. The bottom layer (ca. 15-20 cm) is placed on top of this, and the intermediate layer (ca. 15-20 cm), which should not be inverted, is placed at the top. Thereby the contamination is well shielded against, and impact on fertility is minimised.
Target	Grassed areas and other areas of soil, which have not been tilled since contamination.
Targeted radionuclides	Caesium (plus other radionuclides if edible products are grown).
Scale of application	Can be carried out on a large scale in garden areas by house owners.
Contamination pathway	None (possibly root-uptake in kitchen gardens).
Exposure pathway	Mainly external exposure from contaminated land. Possibly also dose from consumption of contaminated kitchen garden products.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose. As the procedure would often have nearly same effect on dose rate after one week as after two years it could be accomplished over a long period.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent.
• Social constraints	Acceptability of smothering flora and fauna and destruction of garden planting. Aesthetic consequences of landscape/amenity changes.
• Environmental constraints	Soil texture (big rocks), snow covers, and frost may be restrictions.
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment Need for dialogue between owners/workers/public.

Effectiveness:	
• Countermeasure effectiveness	Reduction of dose rate contribution by 80-90 %, if optimised according to contaminant distribution in soil. If edible crops are grown the method may reduce consumption dose, depending on crop root system.
• Factors influencing effectiveness of procedure (Technical)	Size of treated area (large areas will have higher 'surface' DRF). Soil type and conditions (loose soil will be more difficult to treat with the optimal effect). Uniformity of vertical distribution of Cs. Time (downward Cs migration in soil). Contaminant resuspension could possibly have an impact on effectiveness if the method is carried out very early.
• Factors influencing effectiveness of procedure (social)	Compliance (owners/workers/public) with appropriate process of application of countermeasure. Extent of take-up at local/household level as self help measure.
Feasibility:	
• Required specific equipment	Spades.
• Required ancillary equipment	-
• Required utilities and infrastructure	-
• Required consumables	-
• Required skills	Can be carried out by local inhabitants given only little instruction.
• Required safety precautions	Particularly, early after accident and under very dusty conditions respiratory protection and protective clothes may be recommended.
• Other limitations	Contaminants will be brought closer to the groundwater level. The method involves 'hard' work, not all can carry out.
Waste:	
• Amount and type	None
• Possible transport, treatment and storage routes.	-
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter

• Factors influencing averted dose	Consistency in carrying out the procedure over a large area (without treatment, about one-third of the dose rate from an infinitely large open soil area will in the early phase be expected to come from contamination more than 16 m away. However, the shielding provided by e.g., buildings in an urban/industrial area will greatly limit dose rate contributions from afar and thereby make the method more effective considering the relative reduction). Population density and behaviour pattern. Age of persons exposed. If edible crops are grown the method may reduce consumption dose, depending on crop root system.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Influenced by measures taken to protect operators against inhalation of contaminants and contamination of skin/clothes, where required.
Intervention Costs:	
• Equipment	Spade (ca. 15-20 EURO).
• Consumables	-
• Operator time	Ca. 20-30 minutes per m^2.
• Factors influencing costs	Individual work rates. Soil type and conditions (e.g., moisture, season), vegetation, topography, labour costs.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	Public/owner compensation for possible damage to property/amenity.
• Waste cost	None.
• Assumptions	
Side-effect evaluation:	
• Ethical considerations	Potential for self-help. Possible redistribution of dose via groundwater. *In situ* treatment of waste. Free informed consent and compensation of workers. Consent of owners.
• Environmental impact	The procedure brings contamination closer to the groundwater. Cs will however normally be very strongly bound. Soil erosion risk. Future restriction on land use: must not be deep-tilled.
• Agricultural impact	Possible partial loss of soil fertility (though limited). May require fertilisation / replanting.

• Social impact	Maintenance of use of urban spaces Acceptability and potential for conflict regarding selection of areas for treatment. Destruction of gardens or amenity areas. Potential for dispute between neighbours over different applications of countermeasure. Restrictions on further use requiring deep tilling.
• Other side effects, pos. or neg.	Adverse aesthetical effect of treatment. Severely complicates subsequent *removal* of the contamination. Public reassurance issues.
Practical experience	Tested several times after the Chernobyl accident, in ca. 100-200 m^2 plots in CIS.
Key references	Roed et al.: J. Environ. Rad. vol. 45; Hubert et al.: EUR 16530; Andersson: NKS/EKO-5(96)18; Roed et al: Risø-R-828; Andersson & Roed: J. Environ. Rad. 46, 1999.
Comments	It should be mentioned that essentially the same change of soil layers as is carried out by triple digging could be accomplished with machines (e.g., a 'Bobcat' mini-bulldozer), but the practical experience is here very sparse.

Skim-and-burial ploughing (park areas)	
Objective	To reduce the external dose rate in the area (with minimised fertility loss).
Other Benefits	Reduction of ingestion dose if food is produced.
Countermeasure description	Without intervention, it is generally expected that much of an airborne Cs deposition to soil will throughout several years remain distributed in the upper few centimetres of the soil profile. This special plough, which has two plough shares, skims off a thin top soil layer (ca. 5 cm; adjustable) just containing the contamination (the vertical contaminant distribution must be assessed), and buries it at a depth of some 45 cm. The deeper soil layer (ca.5-50 cm) is lifted by the other ploughshare and placed at the top. This layer is not inverted, and the adverse effect of the ploughing on soil fertility is thus minimised. The contamination is shielded well against and brought out of the uptake zone of some plants.
Target	Large open areas (e.g., parks) in urban areas, which have not been tilled since contamination.
Targeted radionuclides	Caesium (plus other radionuclides if edible products are grown).
Scale of application	Achievable on a large scale - ploughs are not readily available, but can be constructed over a period of time.
Contamination pathway	None (possibly root-uptake if food is produced).
Exposure pathway	Mainly external exposure from contaminated land. Possibly also dose from consumption of food products.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose. As the procedure would often have nearly same effect on dose rate after one week as after two years, one set of equipment can treat a large area.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Liability for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	Acceptability of smothering flora and fauna and destruction of planting. Aesthetic consequences of landscape/amenity changes.

• Environmental constraints	Soil texture (big rocks), snow covers, and frost may be restrictions. Soil should not be too loose (sandy). Application of fertilisers may be called for. Soil depth >0.5 m required for skim and burial ploughing
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by ca. 83-92 %, if optimised according to contaminant distribution in soil. Internal dose reduction: all contamination in upper 20 cm can be reduced by 90-95 %. Consumption dose reduction depends on e.g., root system of crops.
• Factors influencing effectiveness of procedure (Technical)	Soil type and conditions ('Loose' soil will be more difficult to treat optimally). Optimisation of layer depths. Uniformity of vertical distribution of Cs. Time (downward Cs migration in soil). Contaminant resuspension could possibly have an impact on effectiveness if the method is carried out very early.
• Factors influencing effectiveness of procedure (social)	Compliance (owners/workers/public) with appropriate process of application of countermeasure
Feasibility:	
• Required specific equipment	Skim-and-burial plough (these are not readily available).
• Required ancillary equipment	Powerful tractor.
• Required utilities and infrastructure	Roads for plough transport.
• Required consumables	Petrol.
• Required skills	Can be carried out by agricultural workers, who are familiar with ploughing, but must be instructed carefully about the objective.
• Required safety precautions	Particularly, early after accident and under very dusty conditions respiratory protection and protective clothes may be recommended.
• Other limitations	Contaminants will be brought closer to the groundwater level. Shallow fertile soil layer
Waste:	
• Amount and type	None

• Possible transport, treatment and storage routes.	-
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter
• Factors influencing averted dose	Consistency in carrying out the procedure over a large area. Population density and behaviour pattern. Age of persons exposed. If edible crops are grown the method may reduce consumption dose, depending on crop root system.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Influenced by measures taken to protect operators against inhalation of contaminants and contamination of skin/clothes, where required.
Intervention Costs:	
• Equipment	Skim-and-burial plough: ca. 4,000 EURO. Tractor: ca. 50,000 EURO.
• Consumables	Petrol: ca. 15 l ha^{-1}.
• Operator time	Ca. 3 h per ha^{-1} (one operator).
• Factors influencing costs	Operator skills. Soil type and conditions (e.g., moisture, season), vegetation, topography, labour costs.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	-
• Waste cost	None.
• Assumptions	
Side-effect evaluation:	
• Ethical considerations	Need for informed consent from amenity users. Potential redistribution of dose from amenity users to operators and other via groundwater. *In situ* treatment of waste. Free informed consent and compensation of workers Compensation for property/amenity damage/change. Liability cover for unforeseen health or environmental effects.

• Environmental impact	The procedure brings contamination closer to the groundwater. Cs will however normally be very strongly bound. Soil erosion risk. Future restriction on land use: must not be deep-tilled.
• Agricultural impact	Possible partial loss of soil fertility (though limited). May require fertilisation / replanting.
• Social impact	Maintenance of use of urban spaces, although partial change in usage likely (temporary loss of amenity area). Acceptability and potential for dispute regarding selection of areas to be treated
• Other side effects, pos. or neg.	Adverse aesthetical effect of treatment. Severely complicates subsequent *removal* of the contamination. Public reassurance issues.
Practical experience	Tested several times after the Chernobyl accident, in CIS and in Denmark (typically in 1000-2000 m^2 areas).
Key references	Roed et al.: J. Environ. Rad. vol. 33; Hubert et al.: EUR 16530; Andersson et al: NKS-16, ISBN 87-7893-066-9, 2000; Roed et al: Risø-R-828.
Comments	-

Deep ploughing (park areas)	
Objective	To reduce the external dose rate in the area.
Other Benefits	Reduction of ingestion dose if food is produced.
Countermeasure description	Without intervention, it is generally expected that much of the Cs fallout to soil will throughout several years remain distributed in the upper few centimetres of the soil profile. By deep-ploughing with an ordinary single-furrow mouldboard plough to a depth of some 45 cm, the contamination is buried deep in the soil. The contamination is thus shielded well against and it is brought out of the uptake zone of some plants.
Target	Large open urban areas of soil (e.g., parks), which have not been tilled since contamination.
Targeted radionuclides	Caesium (plus other radionuclides if edible products are grown).
Scale of application	Achievable on a large scale.
Contamination pathway	None (possibly root-uptake if food is produced).
Exposure pathway	Mainly external exposure from contaminated land. Possibly also dose from consumption of food products.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose. As the procedure would often have nearly same effect on dose rate after one week as after two years, one set of equipment can treat a large area.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Liabilities for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	Acceptability of smothering flora and fauna and destruction of planting. Aesthetic consequences of landscape/amenity changes.
• Environmental constraints	Soil texture (big rocks), snow covers, and frost may be restrictions. Soil should not be too loose (sandy). Application of fertilisers may be called for. Soil depth >0.5 m required for deep ploughing
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment.
Effectiveness:	

• Countermeasure effectiveness	Reduction of dose rate contribution by ca. 83-90 %. Internal dose reduction: all contamination in upper 20 cm can be reduced by 90-95 %. Consumption dose reduction depends on e.g., root system of crops.
• Factors influencing effectiveness of procedure (Technical)	Soil type and conditions ('Loose' soil will be more difficult to treat to best effect). Uniformity of vertical distribution of Cs. Time (downward Cs migration in soil). Contaminant resuspension could possibly have an impact on effectiveness if the method is carried out very early.
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure
Feasibility:	
• Required specific equipment	Plough (readily available in some European areas, and can be made available in others).
• Required ancillary equipment	Tractor.
• Required utilities and infrastructure	Roads for plough transport.
• Required consumables	Petrol.
• Required skills	Can be carried out by agricultural workers, who are familiar with ploughing, but must be instructed carefully about the objective.
• Required safety precautions	Particularly, early after accident and under very dusty conditions respiratory protection and protective clothes may be recommended.
• Other limitations	Contaminants will be brought closer to the groundwater level. Thin fertile soil layer.
Waste:	
• Amount and type	None
• Possible transport, treatment and storage routes.	-
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter
• Factors influencing averted dose	Consistency in carrying out the procedure over a large area. Population density and behaviour pattern. Age of persons exposed. If edible crops are grown the method may reduce consumption dose, depending on crop root system.

• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Influenced by measures taken to protect operators against inhalation of contaminants and contamination of skin/clothes, where required.
Intervention Costs:	
• Equipment	Plough: ca. 2,000 EURO. Tractor: ca. 50,000 EURO.
• Consumables	Petrol: ca. 15 l ha^{-1}.
• Operator time	Ca. 1.5 h per ha^{-1} (one operator).
• Factors influencing costs	Operator skills. Soil type and conditions (e.g., moisture, season), vegetation, topography, labour costs.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	-
• Waste cost	None.
• Assumptions	
Side-effect evaluation:	
• Ethical considerations	Need for informed consent from amenity users. Potential redistribution of dose from amenity users to operators and other via groundwater. Free informed consent of workers to risks of radiation exposure. Consent of public/private owners. Compensation for increased radiation dose (workers). Liability cover for unforeseen health or environmental effects.
• Environmental impact	The procedure brings contamination closer to the groundwater. Cs will however normally be very strongly bound. Soil erosion risk. Future restriction on land use: must not be deep-tilled.
• Agricultural impact	Possible loss of soil fertility. May require fertilisation / replanting.
• Social impact	Maintenance of use of urban spaces, although partial change in usage likely (temporary loss of amenity area). Acceptability and potential for dispute regarding selection of areas to be treated.
• Other side effects, pos. or neg.	Adverse aesthetical effect of treatment. Severely complicates subsequent *removal* of the contamination. Public reassurance issues.
Practical experience	Tested widely in CIS and on limited scale in Denmark.

Key references	Hubert et al.: EUR 16530; Andersson et al: NKS-16, ISBN 87-7893-066-9, 2000; Roed et al: Risø-R-828. Vovk et al.: Sci. Tot. Env., 1993.
Comments	-

Shallow ploughing (park areas)	
Objective	To reduce the external dose rate in the area.
Other Benefits	Limited reduction of ingestion dose if food is produced.
Countermeasure description	Without intervention, it is generally expected that much of an airborne Cs deposition to soil will throughout several years remain distributed in the upper few centimetres of the soil profile. By shallow ploughing with an ordinary mouldboard plough to a depth of some 25 cm, the contamination is buried in the soil. The contamination is thus shielded against and it may be brought out of the uptake zone of some plants.
Target	Large open urban areas of soil (e.g., parks), which have not been tilled since contamination.
Targeted radionuclides	Caesium (plus other radionuclides if edible products are grown).
Scale of application	Achievable on a large scale.
Contamination pathway	None (possibly root-uptake if food is produced).
Exposure pathway	Mainly external exposure from contaminated land. Possibly also dose from consumption of food products.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose. As the procedure would often have nearly same effect on dose rate after one week as after two years, one set of equipment can treat a large area.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Liabilities for possible damage to property. Requirement for radiation protection training of workers.
• Social constraints	Acceptability of smothering flora and fauna and destruction of planting. Aesthetic consequences of landscape/amenity changes.
• Environmental constraints	Soil texture (big rocks), snow covers, and frost may be restrictions. Application of fertilisers may be called for. Soil depth >0.3 m required for shallow ploughing
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment.
Effectiveness:	

• Countermeasure effectiveness	Reduction of dose rate contribution by ca. 50-75 %. Internal dose reduction: all contamination in upper 10 cm can be reduced by 80-90 %. Consumption dose reduction depends on e.g., root system of crops.
• Factors influencing effectiveness of procedure (Technical)	Soil type and conditions ('Loose' soil will be more difficult to treat optimally). Uniformity of vertical distribution of Cs. Time (downward Cs migration in soil). Contaminant resuspension could possibly have an impact on effectiveness if the method is carried out very early.
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure.
Feasibility:	
• Required specific equipment	Plough (readily available in European areas, where ploughing is possible).
• Required ancillary equipment	Tractor.
• Required utilities and infrastructure	Roads for plough transport.
• Required consumables	Petrol.
• Required skills	Can be carried out by agricultural workers, who are familiar with ploughing, but must be instructed carefully about the objective.
• Required safety precautions	Particularly, early after accident and under very dusty conditions respiratory protection and protective clothes may be recommended.
• Other limitations	Contaminants will be brought a bit closer to the groundwater level.
Waste:	
• Amount and type	None
• Possible transport, treatment and storage routes.	-
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter
• Factors influencing averted dose	Consistency in carrying out the procedure over a large area. Population density and behaviour pattern. Age of persons exposed. If edible crops are grown the method may reduce consumption dose, depending on crop root system.

• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Influenced by measures taken to protect operators against inhalation of contaminants and contamination of skin/clothes, where required.
Intervention Costs:	
• Equipment	Plough: ca. 2,000 EURO. Tractor: ca. 50,000 EURO.
• Consumables	Petrol: ca. 7 l ha^{-1}.
• Operator time	Ca. 1.2 h per ha^{-1} (one operator).
• Factors influencing costs	Operator skills. Soil type and conditions (e.g., moisture, season), vegetation, topography, labour costs.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	-
• Waste cost	None.
• Assumptions	
Side-effect evaluation:	
• Ethical considerations	Need for informed consent from amenity users. Potential redistribution of dose from amenity users to operators and other via groundwater. Free informed consent of workers to risks of radiation exposure. Compensation for increased radiation dose (workers). Compensation for amenity damage/change. Liability cover for unforeseen health or environmental effects.
• Environmental impact	The procedure brings contamination closer to the groundwater. Cs will however normally be very strongly bound. Future restriction on land use: must not be tilled.
• Agricultural impact	May require seeding/replanting.
• Social impact	Maintenance of use of urban spaces, although partial change in usage likely (temporary loss of amenity area). Acceptability and potential for dispute regarding selection of areas to be treated.
• Other side effects, pos. or neg.	Adverse aesthetical effect of treatment. Severely complicates subsequent *removal* of the contamination. Public reassurance issues.
Practical experience	Tested widely in CIS and on limited scale in Denmark.

Key references	Hubert et al.: EUR 16530; Andersson et al: NKS-16, ISBN 87-7893-066-9, 2000; Roed et al: Risø-R-828. Vovk et al.: Sci. Tot. Env., 1993; Andersson & Roed: J. Environ. Rad. 46, 1999.
Comments	-

Turf harvesting (park areas)	
Objective	To reduce the external dose rate in the area.
Other Benefits	Reduction of ingestion dose from consumption of kitchen garden products, if produced subsequently.
Countermeasure description	Almost invariably, caesium fallout deposited on soil remains in the topmost few centimetres for many years -this is certainly the case on clays and brown earths. Gamma spectrometric analysis of soil core sample sections shows how deep a layer should be removed to maximise dose reduction with minimal impact on soil fertility. The removal may be carried out using a turf-harvester (standard equipment in grass nurseries), which skims of a very thin contaminated topsoil layer (few cm) in rolls or slabs.
Target	Parks with mature organic mat, which have not been tilled since contamination. The mat must be even.
Targeted radionuclides	Caesium (plus other radionuclides if edible products are grown).
Scale of application	Can be carried out on a large scale where equipment is or can be made available.
Contamination pathway	None (possibly root-uptake if food is produced).
Exposure pathway	Mainly external exposure from contaminated land. Possibly also dose from consumption of food products.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. Can still after a decade save a significant fraction of the 70 y dose. As the procedure would often have nearly same effect on dose rate after one week as after two years, one set of equipment can treat a large area.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Requirement for radiation protection training of workers
• Social constraints	Aesthetic consequences of landscape/amenity changes.
• Environmental constraints	The harvesting equipment is very sensitive to stones and rocks. In some cases also frost may be a restriction. Soil should not be covered by snow. Under extreme conditions also area slope (largely depending on operator skills).
• Communication constraints	Need for public explanation of countermeasure
Effectiveness:	

• Countermeasure effectiveness	Reduction of contamination by ca. 65-90 %.
• Factors influencing effectiveness of procedure (Technical)	Optimisation of thickness of removed soil layer (operator skills). Evenness of ground surface. Uniformity of vertical distribution of Cs. Soil texture (the method will only be efficient for soils with mature organic horizon). Time (downward migration of Cs in soil). Contaminant resuspension could possibly have an impact on effectiveness if the method is carried out very early.
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure. Avoidance of turf entering marketplace and being reused.
Feasibility:	
• Required specific equipment	Turf harvester (turf harvesters requiring a tractor also exist).
• Required ancillary equipment	Waste transport truck (or other means of transport) to repository and machinery for constructing repository, depending on waste action scheme.
• Required utilities and infrastructure	Roads to repository, depending on waste action scheme.
• Required consumables	Petrol.
• Required skills	Grass nursery workers or agricultural workers, who are familiar with soil treatment machines and could operate the turf harvester after a few hours of instruction/practice. Care must be taken to remove soil to the optimal depth.
• Required safety precautions	Early after accident and under very dusty conditions respiratory protection and protective clothes may be recommended.
• Other limitations	
Waste:	
• Amount and type	If 2 cm topsoil is removed, this produces a waste corresponding to some 30 kg m^{-2}. Contamination ca. 50 Bq m^{-3} per Bq m^{-2}.
• Possible transport, treatment and storage routes.	Transport by e.g. trucks or rail, depending on waste action scheme. Simple repositories should be constructed. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential.
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter

• Factors influencing averted dose	Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area. If edible crops are grown the method can reduce their contaminant content corresponding to DF.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Doses received around waste repository, depending on waste action scheme (see also separate Chapter). Influenced by measures taken to protect operators against e.g., inhalation, and contamination of skin/ clothes, where required.
Intervention Costs:	
• Equipment	Turf harvester (ca. 8,000 EURO). Waste transport/ treatment equipment (variable).
• Consumables	Ca. 20 l ha^{-1} of petrol (excl. waste transport) at current cost per litre.
• Operator time	Typically some 50 h per ha, plus loading to waste transport truck (ca. 10-20 h per ha), and waste transport and work at repository (depending on chosen options).
• Factors influencing costs	Mainly labour skills, layer depth, vegetation to be removed, and machine size. Distance to equipment, consumables and repository, labour costs. Area size influences cost per m^2.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure.
• Compensation costs	-
• Waste cost	Depends on choice of options (see separate Chapter).
• Assumptions	Availability of the required roads.
Side-effect evaluation:	
• Ethical considerations	Redistribution of dose from park users to operators and populations around waste facilities. Free informed consent and compensation of workers. Compensation for amenity damage/change Waste generation.
• Environmental impact	Soil erosion risk.
• Agricultural impact	Possible partial loss of soil fertility (though minimised). Requires fertilisation / replanting.
• Social impact	Maintenance of use of urban space, with temporary restriction on use. Acceptability and potential for conflict regarding selection of areas for treatment.
• Other side effects, pos. or neg.	Adverse aesthetical effect of treatment. Public reassurance issues.

Practical experience	Tested on relatively large meadows in the CIS.
Key references	Andersson et al: NKS-16, 2000; Roed et al.: Risø-R-828; Hubert et al.: EUR 16530
Comments	

Lawn mowing	
Objective	To reduce the external dose rate in the area.
Other Benefits	Reduction of ingestion dose from consumption of kitchen garden products, if produced.
Countermeasure description	In situations where a large fraction of the contaminants are deposited to a grass cover rather than to soil (as generally expectable in cases of dry deposition to lawns), lawn mowing and removal of the cut grass may prevent much of the contamination from reaching the underlying soil. The grass cutting height should be as low as possible.
Target	Grass-covered areas in, e.g., gardens and parks.
Targeted radionuclides	Caesium (plus other radionuclides if edible products are to be grown at some point).
Scale of application	Can be carried out on a large scale where equipment is or can be made available with short notice.
Contamination pathway	None (possibly root-uptake if food is to be produced).
Exposure pathway	Mainly external exposure from contaminated land. Later, possibly also dose from consumption of food products.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. As the natural transfer of contamination from grass to soil has a half-life of only few weeks (depending largely on the amount of rainfall), the lawn mowing must be carried out soon after the contamination (before first heavy rainfall).
Constraints	
• Legal constraints	Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	-
• Environmental constraints	The lawn mowing equipment is very sensitive to stones and rocks. The lawn should not be covered by snow.
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment if there is competition for application due to scarce resources.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by ca. 50-90 % (assuming dry contaminant deposition).

• Factors influencing effectiveness of procedure (Technical)	Precipitation during contaminant deposition. Time and amount of precipitation after the contamination occurred (downward migration of Cs to soil). The extent to which soil is covered by grass and the length of grass at time of deposition. Grass cutting height. Evenness of ground surface. Care taken to remove the cut grass.
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure. Extent of take-up at local/household level as self help measure.
Feasibility:	
• Required specific equipment	Lawn mower with clippings collector.
• Required ancillary equipment	Rakes to collect waste if the lawn mower is not equipped with collector. Waste transport truck (or other means of transport) to repository and machinery for constructing repository, depending on waste action scheme.
• Required utilities and infrastructure	Roads to repository, depending on waste action scheme.
• Required consumables	Petrol (assuming that the lawn-mower is petrol-driven).
• Required skills	Could be carried out by local inhabitants and municipal workers, given only little instruction.
• Required safety precautions	Under very dry conditions respiratory protection and protective clothes may be recommended.
• Other limitations	
Waste:	
• Amount and type	Depends on length and density of the grass cover, and cutting height. Perhaps some 1 m^3 per ha. The contamination would then be ca. 10,000 Bq m^{-3} per Bq m^{-2}.
• Possible transport, treatment and storage routes.	Transport by e.g. trucks or rail, depending on waste action scheme. Simple repositories should be constructed. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential.
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter
• Factors influencing averted dose	Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area. If edible crops are grown the method can reduce their contaminant content corresponding to DF.

• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Without special shielding, the dose rate to a waste truck driver in an area contaminated by 1 MBq m^{-2} of ^{137}Cs may be as high as 50 µSv h^{-1} (compared with ca. 12 µSv d^{-1} typically received by living in the area). Doses received around waste repository, depending on waste action scheme (see also separate Chapter). Influenced by measures taken to protect operators against e.g., inhalation, and contamination of skin/ clothes, if required.
Intervention Costs:	
• Equipment	Ordinary petrol-operated household lawn mower with collector (ca. 1000 EURO). Waste transport/ treatment equipment (variable).
• Consumables	Ca. 25 l ha^{-1} of petrol (excl. waste transport) at current cost per litre.
• Operator time	Typically some 15 h per ha, plus loading to waste transport truck (not highly time-consuming if the lawn mower has a collector). Ca. 20-40 h per ha should be added if grass is collected manually by rakes. Time for waste transport and work at repository depending on chosen options.
• Factors influencing costs	Individual work rate, equipment type (need for use of rakes). Distance to equipment, consumables and repository, labour costs. Area size influences cost per m^2.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	-
• Waste cost	Depends on choice of options (see separate Chapter).
• Assumptions	Availability of the required transport roads.
Side-effect evaluation:	
• Ethical considerations	Re-distribution of dose from users of urban spaces to operators and populations around waste facilities. Potential for self-help. Free informed consent of workers and consent of private owners. Compensation for amenity damage/change. Environmental consequences of waste generation.
• Environmental impact	-
• Agricultural impact	-

• Social impact	Maintenance of use of urban spaces but with temporary loss of established amenity meadows. Acceptability and potential for dispute regarding waste disposal sites, and regarding prioritisation/selection of areas to be treated. Potential for dispute between neighbours over different applications of countermeasure.
• Other side effects, pos. or neg.	The grass is cut. Public reassurance issues.
Practical experience	Tested on a small scale in Europe.
Key references	Andersson: EKO-5, 1996; Roed et al.: Risø-R-828; Hubert et al.: EUR 16530; Maubert et al: Sci. Tot. Env., 1993; Andersson & Roed: J. Environ. Rad. 46, 1999.
Comments	

Pruning or removal of trees and shrubs	
Objective	To reduce the external dose rate in the area.
Other Benefits	-
Countermeasure description	If deposition occurs *without* precipitation, trees or shrubs (particularly if in leaf) may receive relatively high levels of contamination. The (partial) removal of trees/shrubs from gardens may therefore significantly reduce the dose rate to inhabitants immediately after the contamination has occurred. However, the contamination on trees/shrubs in leaf during deposition will (particularly for deciduous species) over the first year decline, often by several orders of magnitude through natural processes (precipitation / leaf fall). Through root-uptake, the level is expected to slowly build up after that (if the ground is not treated), to a maximum after 10-20 years of a few % of the initial contamination on the tree.
Target	Highly contaminated garden or park areas with trees and shrubs (in leaf).
Targeted radionuclides	Caesium.
Scale of application	Can be carried out on a large scale where equipment is or can be made available.
Contamination pathway	None.
Exposure pathway	External exposure from contaminated trees and shrubs. Possibly exposure from ingestion of e.g., apples, berries.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. The pruning or removal should be carried out within weeks after the contamination (and before the first leaf fall).
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Liability for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	Acceptability of removal of shrubs/trees. Aesthetic consequences of landscape/amenity changes.
• Environmental constraints	-
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment.
Effectiveness:	

• Countermeasure effectiveness	Reduction of contamination in principle proportional to the fraction of the tree/shrub removed.
• Factors influencing effectiveness of procedure (Technical)	Degree of pruning or removal. The leaves/ needles are the part that is most important to remove.
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure. Extent of take-up at local/household level as self help measure.
Feasibility:	
• Required specific equipment	Depends on the desired degree of removal. E.g., chainsaws, cutters, axes, pruning knives.
• Required ancillary equipment	Ropes, ladders for tall trees. Waste transport truck (or other means of transport) to repository and machinery for further treatment, depending on waste action scheme.
• Required utilities and infrastructure	Power supply for chainsaws, roads to repository, depending on waste action scheme.
• Required consumables	Petrol for waste transport
• Required skills	Skilled personnel (e.g., forestry workers, tree surgeons or gardeners) with experience in felling trees would be preferable, although the procedure could in principle often also be carried out by local inhabitants.
• Required safety precautions	Respiratory protection and protective clothes recommended. Safety helmets. For tall trees: lifeline.
• Other limitations	
Waste:	
• Amount and type	Highly variable - depends on season, density and type of vegetation and extent of pruning or felling. Normally large volumes.
• Possible transport, treatment and storage routes.	Transport by e.g. trucks or rail, depending on waste action scheme. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential.
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter. In addition to averted external dose, also the production of e.g., contaminated fruit may be reduced.

• Factors influencing averted dose	Whether or not trees/shrubs are in leaf at contamination. Time and amount of precipitation during/since contamination. Window area (much of the radiation from trees will in dwellings pass through thin windows rather than thick brick walls). Trees and shrubs that are not deciduous are most important to treat, as the contamination on these can contribute to external dose over a longer period. However, they do not produce edible fruit. Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area. Doses received during waste treatment, depending on waste action scheme (see also separate Chapter). Influenced by measures taken to protect operators against e.g., inhalation, and contamination of skin/ clothes.
Intervention Costs:	
• Equipment	E.g., chainsaws (ca. 200-1000 EURO), cutters (ca. 100 EURO), axes (ca. 100 EURO). Rope (30 EURO), ladder (200 EURO). Waste transport/ treatment equipment (variable).
• Consumables	Petrol for waste transport (depending on distance) at current cost per litre.
• Operator time	Highly variable. Possibly some 10-50 h per 500 m^2 of 'ordinary' garden area, incl. loading to waste transport truck, but excl. waste transport and treatment.
• Factors influencing costs	Labour skills, work rates, season, vegetation height (need for ladders), type of vegetation to be removed, degree of removal, applied equipment type. Distance to equipment, consumables and waste storage, labour costs. Area size influences cost per m^2.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	Public/owner compensation for possible damage to property/amenity.
• Waste cost	Depends on choice of options (see separate Chapter).
• Assumptions	Availability of the required roads.
Side-effect evaluation:	

• Ethical considerations	Re-distribution of dose from users of urban spaces to operators and populations around waste facilities. Potential for self help. Free informed consent of workers and consent of public/private owners. Compensation for property/amenity damage/change. Environmental impact of waste.
• Environmental impact	Possible adverse impact on bio-diversity.
• Agricultural impact	-
• Social impact	Maintenance of use of urban spaces – some changes of usage likely. Acceptability and potential for dispute regarding basis of selection of areas to be treated. Potential for dispute between neighbours over different applications of countermeasure.
• Other side effects, pos. or neg.	Adverse aesthetical effect of treatment. Public reassurance issues.
Practical experience	Tested on a small scale in Europe after the Chernobyl accident.
Key references	Andersson: NKS/EKO-5(96)18; Roed et al.: Risø-R-828; Guillitte & Willdrodt: Sci. Tot. Env., 1993; Schell et al.: Health Phys., 70(3), 1996; Andersson & Roed: J. Environ. Rad. 46, 1999.
Comments	Even if the averted dose due to the operation is limited, it may be necessary to remove some vegetation in a garden to enable subsequent soil removal.

2.3 Countermeasures for reduction of dose from contaminated walls of dwellings

High-pressure water hosing of walls	
Objective	To reduce external dose in the area
Other Benefits	
Countermeasure description	Using pressure-washing equipment, water may be applied to a wall at a pressure of some 150 bar. This will loosen contamination from the wall and wash it off. A continuous water flow should be applied on the wall to transport contamination to the ground. The washing must start at the top of the wall.
Target	Highly contaminated (e.g., brick, concrete or sandstone) outer walls of residential or industrial buildings. Wooden walls can in some cases also be treated in this case, however it must be demonstrated that the water will not penetrate the wall.
Targeted radionuclides	Caesium.
Scale of application	Could be carried out in selected densely populated areas.
Contamination pathway	None
Exposure pathway	External exposure.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. The immediate effect (DF) will decrease with time of application.
Constraints	
• Legal constraints	Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	-
• Environmental constraints	Frost (may require heated water). Walls must be water-proof.
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment.
Effectiveness:	
• Countermeasure effectiveness	Expected reduction of contamination by 35-80 %. Immediately after the contaminating event the effect of the countermeasure is greatest. Using hot water and detergent aids decontamination. Even after a decade, 50-75 % of the contamination can be removed.

• Factors influencing effectiveness of procedure (Technical)	Contaminant aerosol type (size, solubility). That the procedure described above is followed (operator skills). Amount of water/time used and pressure. Increased water temperature (60-80 °C) and adding detergent will increase effect. Wall material generally has little influence.
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure. Extent of take-up at local/household level as self-help measure.
Feasibility:	
• Required specific equipment	Hose pipe, turbo nozzle, mobile pressure washer (typical weight ca. 80 kg).
• Required ancillary equipment	Transport vehicles for equipment. Scaffolds or mobile lifts for tall buildings.
• Required utilities and infrastructure	Water supply (water may be pumped from a lake if tap/hydrant is not available).
• Required consumables	Power supply (petrol-driven mobile generator may be applied if power is not available). Petrol for transport vehicles.
• Required skills	The experience of specialists from decontamination firms can be exploited. Personnel from fire brigades, construction workers and personnel from civil defence can with proper instruction do the work.
• Required safety precautions	For tall buildings: lifeline and safety helmets. Water proof safety clothing and safety glasses should be used. The water will suppress much of the dust.
• Other limitations	
Waste:	
• Amount and type	Generates some 20 l m^{-2} of liquid waste, with ca. 0.4 kg m^{-2} of solid waste containing nearly all contamination. Solid waste contamination level: ca. 4000 Bq m^{-3} per Bq m^{-2}). Waste is practically impossible to collect.
• Possible transport, treatment and storage routes.	-
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter.

• Factors influencing averted dose	Consistency in procedure application, care taken to wash contamination to the ground and not just translocate on the wall. The lower part of the wall should be cleaned particularly well, as this is closest to any persons outside and close to the building. The horizontal surfaces below the wall should ideally be treated *afterwards*. Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area (possibly even more, depending on building height, landscape, etc.). Influenced by protection of workers with waterproof safety clothing.
Intervention Costs:	
• Equipment	Cost of mobile pressure washer with turbo nozzle: typically about 3000 EURO. (Or fire-hosing equipment ca. 1000 EURO). Variable costs for scaffolding/lifts according to need.
• Consumables	Ca. 20 l per m^2 of water for mobile pressure washing or fire-hosing; power: typically 400 V at 12 A (with petrol-driven generator: ca. 4 l of petrol per hour) and petrol for equipment transport; at current prices.
• Operator time	Pressure washing: Ca. 1-2 min. per m^2 (fire-hosing: 0.1-0.2 min. per m^2) plus variable time for setting up scaffolds/transport.
• Factors influencing costs	Distance to equipment and consumables. Need for scaffolds /mobile lifts. Operator skills. Labour costs. Area size influences cost per m^2.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	-
• Waste cost	-
• Assumptions	Availability of the required roads for transport of equipment, availability of water resources in the area.
Side-effect evaluation:	
• Ethical considerations	Redistribution of dose from users of urban spaces to operators and waste water treatment workers. Free informed consent of workers and consent of public/private owners. Compensation for any property damage Environmental consequences of waste.
• Environmental impact	If no drain the water may damage basements.

• Agricultural impact	-
• Social impact	Maintenance of use of urban spaces. Acceptability and potential for dispute regarding basis of selection of areas to be treated.
• Other side effects, pos. or neg.	The surface is cleaned. If the wall is plastered repair of the plaster is often needed. Public reassurance issues.
Practical experience	Tested on realistic scale on selected walls in the CIS and Europe, after the Chernobyl accident.
Key references	Roed & Andersson: J. Environ. Rad. vol. 33, no.2; Andersson: NKS/EKO-5(96)18; Roed et al.: Risø-R-828; Hubert et al.: EUR 16530; Andersson & Roed: J. Environ. Rad. 46, 1999.
Comments	

Sandblasting of walls	
Objective	To reduce external dose in the area
Other Benefits	
Countermeasure description	Sandblasting of walls will remove a thin surface layer, together withthe contamination. To eliminate the risk of contaminant translocation on the wall the sandblasting must start at the top of the wall. Wet sandblasting is recommended, although dry sandblasting is generally almost as efficient. However, the resuspension of contaminants is difficult to control with dry sandblasting.
Target	Highly contaminated outer (e.g.,brick, concrete or stone) walls of residential or industrial buildings.
Targeted radionuclides	Caesium.
Scale of application	Could be carried out in selected densely populated areas.
Contamination pathway	None
Exposure pathway	External exposure.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. The effectiveness of cleaning decreases with time elapsed since contamination occurred.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Liability for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	Aesthetic consequences of architecture/amenity changes.
• Environmental constraints	Frost (may require heating of water). Walls must be water-resistant.
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Expected reduction of contamination by 75-85 %.

• Factors influencing effectiveness of procedure (Technical)	That the procedure described above is followed (operator skills). Amount of water and sand (time) used per m^2 and pressure. Type of sand applied (preferably quartz-sand (0.5-2 mm)). Wall material generally has little influence (e.g., clay, concrete, stone, plastered wall, metal).
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure.
Feasibility:	
• Required specific equipment	Hose pipe, mobile pressure washer (typical weight ca. 80 kg), sandblasting device injecting sand into the water stream.
• Required ancillary equipment	Transport vehicles for equipment. Scaffolds or mobile lifts for tall buildings.
• Required utilities and infrastructure	Water supply (water may be pumped from a lake if tap/hydrant is not available).
• Required consumables	Power supply (petrol-driven mobile generator may be applied if power is not available). Petrol for transport vehicles. Sand.
• Required skills	The experience of specialists from decontamination firms can be exploited. Personnel from fire brigades, construction workers and personnel from civil defence can with proper instruction do the work.
• Required safety precautions	For tall buildings: lifeline and safety helmets. Water proof safety clothing and safety glasses should be used. The wet sandblasting method will produce relatively little dust, but respiratory protection is still required.
• Other limitations	
Waste:	
• Amount and type	Generates some 3 kg m^{-2} of solid waste (containing nearly all contamination) in ca. 50 l m^{-2} water, which is impossible to collect.
• Possible transport, treatment and storage routes.	-
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter.

• Factors influencing averted dose	Consistency in procedure application, care taken to move contamination to the ground and not just translocate on the wall. The horizontal surface below the wall should ideally be treated *afterwards*. Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area (possibly even more, depending on building height, landscape, etc.). Influenced by protection of workers with waterproof safety clothing.
Intervention Costs:	
• Equipment	Cost of mobile pressure washer: typically ca. 3000 EURO. Variable costs for scaffolding/lifts according to need.
• Consumables	Ca. 50 l per m^2 of water for mobile pressure washing; power: typically 400 V at 12 A (with petrol-driven generator: ca. 4 l of petrol per hour) and petrol for equipment transport; at current prices. Ca. 2 kg m^{-2} Sand.
• Operator time	Ca. 3-4 min. per m^2 plus variable time for setting up scaffolds/transport.
• Factors influencing costs	Distance to equipment and consumables. Need for scaffolds /mobile lifts. Operator skills. Labour costs. The wall may require subsequent surface treatment (e.g., plastering).
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	Public/owner compensation for possible damage to property/amenity.
• Waste cost	-
• Assumptions	Availability of the required roads for transport of equipment, availability of water resources and sand in the area.
Side-effect evaluation:	
• Ethical considerations	Redistribution of dose from users of urban spaces to operators and waste water workers. Free informed consent of workers and consent of public/private owners. Compensation for property/amenity damage/changes. Environmental consequences of waste generation and treatment.
• Environmental impact	If no drain the water from wet sandblasting may damage basements.

• Agricultural impact	-
• Social impact	Maintenance of use of urban spaces. Acceptability and potential for conflict regarding basis of selection of areas to be treated.
• Other side effects, pos. or neg.	The surface is cleaned. Public reassurance issues.
Practical experience	Tested on realistic scale on selected walls in the CIS and Europe, after the Chernobyl accident.
Key references	Roed & Andersson: J. Environ. Rad. vol. 33, no.2; Andersson: NKS/EKO-5(96)18; Roed et al.: Risø-R-828; Hubert et al.: EUR 16530.
Comments	

Ammonium treatment of walls	
Objective	To reduce external dose in the area
Other Benefits	
Countermeasure description	An ammonium nitrate solution in water (0.1 M) is made in a vessel. Using a pump and a hose, the solution is sprayed on to the wall at low pressure. The ammonium ion exchanges withcaesium ions, and thus reduces the wall contamination. A continuous water flow should be applied on the wall to transport contamination to the ground. The washing must start at the top of the wall. The wall is subsequently washed with clean water to minimise corrosion.
Target	Highly contaminated outer (e.g., brick, concrete or stone) walls of residential or industrial buildings.
Targeted radionuclides	Caesium.
Scale of application	Could be carried out in selected densely populated areas.
Contamination pathway	None
Exposure pathway	External exposure.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. The immediate effect (DF) will decrease with time elapsed before application.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Restrictions on chemical use. Liability for possible damage to property. Ownership and access to property. Requirement for radiation protection training of worker.
• Social constraints	Aesthetic consequences of architecture/amenity changes, e.g. colour change on painted metal surfaces.
• Environmental constraints	Frost (may require hot water). Walls must be water-resistant.
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by typically ca. 35-50 % immediately after contamination, and 10-25 % a few years after.

• Factors influencing effectiveness of procedure (Technical)	Spraying time. Contaminant aerosol type (chemical form of caesium). That the procedure described above is followed (operator skills). Best effect on bricks fired at high temperature (>1000°C).
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure.
Feasibility:	
• Required specific equipment	Water hose, pump.
• Required ancillary equipment	Transport vehicles for equipment. Scaffolds or mobile lifts for tall buildings. Vessel for mixing the solution.
• Required utilities and infrastructure	Water supply (water may be pumped from a natural water source if tap/hydrant is not available). Power supply (petrol-driven mobile generator may be used if power is not available). Petrol for transport vehicles.
• Required consumables	Ammonium nitrate.
• Required skills	Can be carried out by e.g., civil defence, construction workers or fire brigade. Only little instruction required.
• Required safety precautions	For tall buildings: lifeline and safety helmets. Water-proof safety clothing recommended.
• Other limitations	
Waste:	
• Amount and type	Generates some 6 l m^{-2} of liquid waste. Waste is impossible to collect.
• Possible transport, treatment and storage routes.	-
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter.
• Factors influencing averted dose	Consistency in procedure application, care taken to wash contamination to the ground and not just translocate on the wall. The bottom part of the wall should be cleaned particularly well, as this is closest to any persons outside and close to the building. The horizontal surface below the wall should ideally be treated *afterwards*. Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area.

• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area (possibly even more, depending on building height, landscape, etc.). Influenced by protection of workers with waterproof safety clothing.
Intervention Costs:	
• Equipment	Cost of hose pipe and pump: typically ca. 1000 EURO. Variable costs for scaffolding/lifts according to need. Vessel for mixing the solution (ca. 100 EURO).
• Consumables	Ca. 6 l per m^2 of water. Ca. 8 g ammonium nitrate per l solution, at current price. Petrol for equipment transport; at current prices.
• Operator time	Ca. 5 min. per m^2 plus variable time for setting up scaffolds/transport.
• Factors influencing costs	Distance to equipment and consumables. Need for scaffolds /mobile lifts. Operator skills. Labour costs.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	Public/owner compensation for possible damage to property/amenity.
• Waste cost	-
• Assumptions	Availability of the required roads for transport of equipment, availability of water resources in the area.
Side-effect evaluation:	
• Ethical considerations	Redistribution of dose from users of urban space to operators and waste water workers. Free informed consent of workers to risks of radiation exposure and/or chemical exposure. Consent of public/private owners. Compensation for property/amenity damage/change. Liability for unforeseen health or property effects. Environmental consequences of waste generation and treatment (chemical and radioactive).
• Environmental impact	If no drain the water may damage basements. The ammonium/nitrate may reach the groundwater.
• Agricultural impact	-
• Social impact	Maintenance of use of urban space. Acceptability and potential for dispute regarding basis of selection of areas to be treated.

• Other side effects, pos. or neg.	Public reassurance issues. Ammonium nitrate can corrode steel surfaces.
Practical experience	Tested on realistic scale on selected walls in the CIS and Europe, after the Chernobyl accident.
Key references	Roed & Andersson: J. Environ. Rad. vol. 33, no.2; Andersson: NKS/EKO-5(96)18; Roed et al.: Risø-R-828; Hubert et al.: EUR 16530; Sandalls: AERE report12355, 1987.
Comments	

Mechanical abrasion of wooden walls	
Objective	To reduce external dose in the area
Other Benefits	
Countermeasure description	The contamination level on a (painted) wooden wall may be reduced by abrasion using an electric hand held drill. This grinding procedure, which is commonly used to clean surfaces prior to painting, removes a thin surface layer (a few mm) and the concomitant contamination.
Target	Highly contaminated (painted) wooden outer walls of residential or industrial buildings.
Targeted radionuclides	Caesium.
Scale of application	Could be carried out in selected densely populated areas.
Contamination pathway	None
Exposure pathway	External exposure.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. The immediate effect (DF) may decrease with time of application, as horizontal contaminant migration may occur in the wall. This decrease is, however, unlikely to be significant on painted walls.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Liability for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	Acceptability of distribution of contaminated paint particles into air. Aesthetic consequences of architecture changes.
• Environmental constraints	
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by some 35-60 %.
• Factors influencing effectiveness of procedure (Technical)	Contaminant aerosol size (large particles may be more easily removed). Operator skills and degree of abrasion. Permeability of wall material (time).

• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure. Extent of take-up at local/household level as self help measure.
Feasibility:	
• Required specific equipment	Hand-held drill mounted with sandpaper discs or steel wool for grinding (a sander).
• Required ancillary equipment	Scaffolds or mobile lifts for tall buildings. Transport vehicles for equipment.
• Required utilities and infrastructure	Power supply (petrol-driven mobile generator may be applied if power is not available). Petrol for transport vehicles.
• Required consumables	Steel wool or sandpaper to be mounted on the drill.
• Required skills	Can be carried out by e.g., civil defence, construction workers or fire brigade. Very little instruction required.
• Required safety precautions	For tall buildings: lifeline and safety helmets. Respiratory protection is essential.
• Other limitations	
Waste:	
• Amount and type	Ca. 100 g m^{-2}, which is impossible to collect.
• Possible transport, treatment and storage routes.	-
• Factors influencing waste issues	-
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter.
• Factors influencing averted dose	The horizontal surface below the wall should ideally be treated *afterwards*. Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area (possibly even more, depending on building height, landscape, etc.). Influenced by respiratory protection of workers.
Intervention Costs:	
• Equipment	Cost of sander: ca. 100 EURO.
• Consumables	Steel wool or sandpaper (ca. 1-2 EURO per m^2. Petrol for equipment transport - at current prices.

• Operator time	Ca. 0.5 h per m^2 plus variable time for setting up scaffolds/transport.
• Factors influencing costs	Distance to equipment and consumables. Need for scaffolds /mobile lifts. Operator skills. Labour costs.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	Public/owner compensation for possible damage to property/amenity. It should, however, be stressed that the impacts are no more than if the building was simply to be repainted. Labour costs may be higher to compensate workers for their exposure to higher risks.
• Waste cost	-
• Assumptions	Availability of the required roads for transport of equipment.
Side-effect evaluation:	
• Ethical considerations	Free informed consent of workers. Consent of public/private owners. Compensation for property/amenity damage/change. Liability cover for unforeseen health or property effects.
• Environmental impact	-
• Agricultural impact	-
• Social impact	Maintenance of use of urban spaces. Acceptability and potential for dispute regarding basis of selection of areas to be treated and dispersion of contaminated paint particles. Potential for dispute between neighbours over different applications of countermeasure.
• Other side effects, pos. or neg.	Public reassurance issues.
Practical experience	Tested on realistic scale on selected walls in the CIS, after the Chernobyl accident.
Key references	Hubert et al.: EUR 16530; Roed et al.: Risø-R-828.
Comments	Nails may need to be punched in or extracted before the operation. Resurfacing (e.g., painting) generally required after the operation (variable extra costs).

2.4 Countermeasures for reduction of dose from contaminated roofs of dwellings

High-pressure water hosing of roofs	
Objective	To reduce external dose in the area
Other Benefits	
Countermeasure description	Using pressure-washing equipment, water may be applied to a roof at a pressure of some 150 bar. This will loosen contamination from the roof and wash it off. A continuous water flow should be applied to the roof to transport the contamination to the drains. The washing must start at the top of the roof. Alternatively, fire-hosing at hydrant pressure may be applied instead, with somewhat less effect.
Target	Contaminated roofs of residential or industrial buildings.
Targeted radionuclides	Caesium.
Scale of application	Can be carried out on a large scale.
Contamination pathway	None
Exposure pathway	External exposure.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. May still after a decade save a significant fraction of the 70 y dose, depending on roof material and removable debris/growth.
Constraints	
• Legal constraints	Liability for possible damage to property (flooding). Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	-
• Environmental constraints	Frost (may require heated water). The roof construction must resist water at high pressure.
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment.

Effectiveness:	
• Countermeasure effectiveness	Expected reduction of contamination by 35-80 %, depending on water temperature. Immediately after the contamination the effect is generally greatest. Using hot water and detergent improves the effect considerably. Even after a decade this will reduce contamination by 50-75 %. (lowest value for slate, clay and concrete roofs, highest value for silicon-treated slate, and possibly even higher for aluminium/ steel).
• Factors influencing effectiveness of procedure (Technical)	Contaminant aerosol type (size, solubility). That the procedure described above is followed (operator skills). Roof material (see above). Amount of water/time used and pressure. Increased water temperature (60-80 °C) and adding detergent will increase the effect . As time passes, some of the contamination will become more firmly fixed to the roof material. If a surface layer of moss/algae covers the roof at the time of deposition, almost all the contamination may be removable.
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure
Feasibility:	
• Required specific equipment	Hose pipe, turbo nozzle, mobile pressure washer (typical weight ca. 80 kg).
• Required ancillary equipment	Transport vehicles for equipment and waste. Scaffolds or mobile lifts.
• Required utilities and infrastructure	Water supply (water may be pumped from a lake if tap/hydrant is not available). Transport roads.
• Required consumables	Power supply (petrol-driven mobile generator may be applied if power is not available). Petrol for transport vehicles.
• Required skills	The experience of specialists from decontamination firms can be exploited. Personnel from fire brigades, construction workers and personnel from civil defence can, with instruction, do the work.
• Required safety precautions	Lifeline. Safety helmets. Water-proof safety clothing and safety glasses should be used. The water will suppress much of the dust. Should not be carried out as self-help, due to the risk of falling from the roof.
• Other limitations	
Waste:	

• Amount and type	Generates some 20 l m^{-2} of liquid waste, with ca. 0.2 kg m^{-2} of solid waste containing nearly all contamination. Solid waste contamination level: ca. 7000 Bq m^{-3} per Bq m^{-2}).
• Possible transport, treatment and storage routes.	After filtration in a simple filter the water can be disposed of. Transport of (solid) waste by e.g. trucks, depending on waste action scheme. Simple repositories should be constructed. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential.
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter.
• Factors influencing averted dose	Consistency in procedure application. Care taken to wash contamination to the roof gutter and not just translocate it on the roof. The horizontal surface below the roof should ideally be treated *afterwards* if there is no roof gutter. Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area. Special care must be taken to clean roof gutters and drain pipes. Industrial buildings often have light (not well shielding) roof constructions, and the often little slope of the roof may give relatively high contamination level.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area (possibly even more, depending on roof height, landscape, etc.). Influenced by protection of workers with waterproof safety clothing.
Intervention Costs:	
• Equipment	Cost of mobile pressure washer with turbo nozzle: typically ca. 3000 EURO. (Or fire-hosing equipment ca. 1000 EURO). Variable costs for scaffolding/lifts according to need.
• Consumables	Ca. 20 l per m^2 of water for mobile pressure washing or fire-hosing; power: typically 400 V at 12 A (with petrol-driven generator: ca. 4 l of petrol per hour) and petrol for equipment/waste transport; at current prices.
• Operator time	Pressure washing: Ca. 1-2 min. per m^2 (fire-hosing: 0.1-0.2 min. per m^2) plus variable time for setting up scaffolds/transport.
• Factors influencing costs	Distance to equipment and consumables. Type and size of scaffolds /mobile lifts. Operator skills. Labour costs.

• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	-
• Waste cost	-
• Assumptions	Availability of the required roads for transport of equipment, availability of water resources in the area.
Side-effect evaluation:	
• Ethical considerations	Re-distribution of dose from users of urban spaces to operators and populations around waste facilities. Free informed consent of workers and consent of public/private owners. Compensation for possible property damage. Environmental consequences of waste generation and treatment.
• Environmental impact	-
• Agricultural impact	-
• Social impact	Maintenance of use of urban spaces. Acceptability and potential for dispute regarding waste disposal sites, and regarding prioritisation/selection of areas to be treated.
• Other side effects, pos. or neg.	The surface is cleaned. Public reassurance issues. Some types of roofing may require subsequent treatment to ensure water impermeability.
Practical experience	Tested on realistic scale on selected roofs of different types in the CIS and Europe, after the Chernobyl accident.
Key references	Roed & Andersson: J. Environ. Rad. vol. 33, no.2; Andersson: NKS/EKO-5(96)18; Roed et al.: Risø-R-828; Hubert et al.: EUR 16530; Andersson & Roed: J. Environ. Rad. 46, 1999.
Comments	Care must be taken not to block drains with moss, etc.

Roof cleaning by cleaning device	
Objective	To reduce external dose in the area
Other Benefits	
Countermeasure description	Commercially available rotating brush driven by compressed air at 700 l min^{-1} (water at ordinary mains pressure). Cleaning is carried out in a closed (shielded) 'box' system. The device is mounted on an extendable rod that allows operation from the top of the roof or, in the case of single-storey buildings, from the ground.
Target	Contaminated roofs of residential or industrial buildings.
Targeted radionuclides	Caesium.
Scale of application	Can be carried out on a large scale where equipment is or can be made available.
Contamination pathway	None
Exposure pathway	External exposure.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. May still after a decade save a significant fraction of the 70 y dose, depending on roof material and removable debris/growth.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Local authority liabilities for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	-
• Environmental constraints	Frost (may require heated water).
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	

• Countermeasure effectiveness	Reduction of contamination by 50-85 % achievable, depending on water temperature. Immediately after the contamination the effect is generally greatest. Using hot water and detergent improves the effect considerably. Even after a decade this will reduce contamination by 50-75 % (lowest values for slate, clay and concrete roofs, highest values for silicon-treated slate, and possibly even higher for aluminium/ steel).
• Factors influencing effectiveness of procedure (Technical)	Contaminant aerosol type (size, solubility). That the procedure described above is followed (operator skills). Roof material (see above). Amount of water/time used and pressure. Increased water temperature (60-80 °C) will increase the effect. As time passes, some of the contamination will become more firmly fixed to the roof material. If a surface layer of moss/algae covers the roof at the time of deposition, almost all the contamination may be removable.
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure.
Feasibility:	
• Required specific equipment	Roof cleaning device (+ mobile air compressor for generating pressurised air, if not locally readily available).
• Required ancillary equipment	Scaffolds or mobile lifts for operation from the roof. Also waste transport truck to repository and machinery for constructing repository must be available.
• Required utilities and infrastructure	Water supply (water may be pumped from a natural water source if tap/hydrant is not available). Transport roads.
• Required consumables	Power supply (petrol-driven mobile generator may be applied if power is not available). Petrol for transport vehicles.
• Required skills	Can be carried out by one (but more easily by two) unskilled workers given little instruction. Workers could be e.g., civil defence, construction workers or fire brigade.
• Required safety precautions	Lifeline. Safety helmets. Water proof safety clothing recommended. As the cleaning is carried out in closed wet medium the dust (inhalation) hazard is negligible. Should not be carried out as self help, because of the risk of falling from the roof.
• Other limitations	
Waste:	

• Amount and type	Generates some 15 l m^{-2} of liquid waste, with ca. 0.2 kg m^{-2} of solid waste containing nearly all contamination. Solid waste contamination level: ca. 7000 Bq m^{-3} per Bq m^{-2}). Waste may be toxic (asbestos).
• Possible transport, treatment and storage routes.	After filtration in a simple filter the water can be recycled. Transport of (solid) waste by e.g. trucks, depending on waste action scheme. Simple repositories should be constructed. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential.
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter.
• Factors influencing averted dose	Consistency in procedure application. Care taken to wash contamination to the roof gutter and not just translocate it on the roof. The horizontal surface below the roof should ideally be treated *afterwards* if there is no roof gutter. Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area. Special care must be taken to clean roof gutters and drain pipes well. Industrial buildings often have light (not well shielding) roof constructions, and the often little slope of the roof may give relatively high contamination level.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area (possibly even more, depending on roof height, landscape, etc.). Influenced by protection of workers with waterproof safety clothing.
Intervention Costs:	
• Equipment	Roof cleaning device (ca. 6,000 EURO), (+ 1-2,000 EURO for mobile compressor if required and variable costs for scaffolding/lifts according to need).
• Consumables	15 l m^{-2} of water (and 5 l petrol per hour for mobile compressor if required), plus variable costs for petrol for equipment and waste transport, all at current prices.
• Operator time	Estimated to ca. 4-8 minutes per m^2 depending on number of operators (1 or 2), excl. setting up scaffold, waste transport and work at repository.
• Factors influencing costs	Distance to equipment and consumables. Type and size of scaffolds /mobile lifts. Operator skills. Labour costs.

• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	Labour costs may be higher to compensate workers for their exposure to higher risks.
• Waste cost	-
• Assumptions	Availability of the required roads for transport of equipment, availability of water resources in the area.
Side-effect evaluation:	
• Ethical considerations	Redistribution of dose from users of urban spaces to operators and populations around waste facilities. Free informed consent of workers and consent of public/private owners. Liability for health or property effects. Environmental consequences of waste generation.
• Environmental impact	-
• Agricultural impact	-
• Social impact	Maintenance of use of urban spaces. Acceptability and potential for dispute regarding waste disposal sites, and regarding prioritisation/selection of areas to be treated.
• Other side effects, pos. or neg.	The surface is cleaned. Public reassurance issues.
Practical experience	Tested on realistic scale on selected roofs of different types in the CIS, after the Chernobyl accident.
Key references	Roed & Andersson: J. Environ. Rad. vol. 33, no.2; Andersson: NKS/EKO-5(96)18; Roed et al.: Risø-R-828; Roed et al.: Risø-R-870; Hubert et al.: EUR 16530.
Comments	Care must be taken not to block drains with moss, etc.

Roof cleaning with pressurised hot water trolley	
Objective	To reduce external dose in the area
Other Benefits	
Countermeasure description	Rotating nozzles are driven by hot water (ca. 65 °C) at high pressure (typically 150 bar). Cleaning is performed in a closed (shielded) 'box' system. The device is mounted on a trolley that can be drawn up across the roof. Operated from the top of the roof - lowered using the pressure water hose.
Target	Contaminated roofs of residential or industrial buildings.
Targeted radionuclides	Caesium.
Scale of application	Can be carried out on a large scale where equipment is or can be made available.
Contamination pathway	None
Exposure pathway	External exposure.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. May still after a decade save a significant fraction of the 70 y dose, depending on roof material and removable debris/growth.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Liability for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	-
• Environmental constraints	Frost (may require heating of water).
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Reduction of contamination by 50-85 % expectable, depending on water temperature. Immediately after the contamination the effect is generally greatest. Using hot water and detergent improves the effect considerably. Even after a decade this will reduce contamination by 50-75 % (lowest value for slate, clay and concrete roofs, highest value for silicon-treated slate, and possibly even higher for aluminium/ iron).

• Factors influencing effectiveness of procedure (Technical)	Contaminant aerosol type (size, solubility). That the procedure described above is followed (operator skills). Roof material (see above). Amount of water/time used and pressure. Further increased water temperature (to e.g., 80 °C) will increase the effect. As time passes, some of the contamination will become more firmly fixed to the roof material. If a surface layer of moss/algae covers the roof at the time of deposition, almost all the contamination may be removable.
• Factors influencing effectiveness of procedure (social)	Compliance with appropriate process of application of countermeasure.
Feasibility:	
• Required specific equipment	Roof cleaning trolley and high pressure hot water generator.
• Required ancillary equipment	Scaffolds or mobile lifts for operation from the roof. Also waste transport truck to repository and machinery for constructing repository must be available.
• Required utilities and infrastructure	Water supply (water may be pumped from a lake if tap/hydrant is not available). Transport roads.
• Required consumables	Power supply (petrol-driven mobile generator may be applied if power is not available). Petrol for transport vehicles.
• Required skills	Carried out by two (unskilled) workers - one on the rooftop and one on the ground administrating supplies (given little instruction). Workers could be e.g., house owners, fire brigade, civil defence, or professional roof workers.
• Required safety precautions	Lifeline. Safety helmets. Water proof safety clothing recommended. As the cleaning is carried out in closed wet medium the dust (inhalation) hazard is negligible. Should not be carried out as self help, because of the risk of falling from the roof.
• Other limitations	
Waste:	
• Amount and type	Generates some 30 l m^{-2} of liquid waste, with ca. 0.2 kg m^{-2} of solid waste containing nearly all contamination. Solid waste contamination level: ca. 7000 Bq m^{-3} per Bq m^{-2}). Waste may be toxic (asbestos).
• Possible transport, treatment and storage routes.	After filtration in a simple filter the water can be disposed of. Transport of (solid) waste by e.g. trucks or rail, depending on waste action scheme. Simple repositories should be constructed. See separate Chapter for further information.

• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential.
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter.
• Factors influencing averted dose	Consistency in procedure application. Care taken to wash contamination to the roof gutter and not just translocate it on the roof. The horizontal surface below the roof should ideally be treated *afterwards* if there is no roof gutter. Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area. Special care must be taken to clean roof gutters and drain pipes well. Industrial buildings often have light (not well shielding) roof constructions, and the often little slope of the roof may give relatively high contamination level.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area (possibly even more, depending on roof height, landscape, etc.). Influenced by protection of workers with waterproof safety clothing.
Intervention Costs:	
• Equipment	Roof cleaning trolley (ca. 500 EURO), (+ 37,500 EURO for hot water high pressure aggregate and variable costs for scaffolding/lifts according to need).
• Consumables	30 l m^{-2} of water (and 8 l petrol per hour for mobile compressor if required), at current prices. Plus variable costs for petrol for equipment and waste transport, all at current prices.
• Operator time	Estimated to ca. 10 minutes per m^2 for each of 2 workers, excl. setting up scaffold, waste transport and work at repository.
• Factors influencing costs	Distance to equipment and consumables. Type and size of scaffolds /mobile lifts. Operator skills. Labour costs.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	-
• Waste cost	-
• Assumptions	Availability of the required roads for transport of equipment, availability of water resources in the area.

Side-effect evaluation:	
• Ethical considerations	Redistribution of dose from users of urban spaces to operators and populations around waste facilities. Free informed consent and compensation of workers. Consent of public/private owners. Liability cover for unforeseen property damage. Environmental consequences of waste generation.
• Environmental impact	-
• Agricultural impact	-
• Social impact	Maintenance of use of urban areas. Acceptability and potential for dispute regarding waste disposal sites, and regarding prioritisation/selection of areas to be treated.
• Other side effects, pos. or neg.	The surface is cleaned. Public reassurance issues. Some types of roofing may require subsequent treatment to ensure water impermeability.
Practical experience	Tested on realistic scale on selected roofs of different types in the CIS, after the Chernobyl accident.
Key references	Andersson et al.: IAEA rep. RER/9/059.
Comments	Care must be taken not to block drains with moss, etc.

Change of roof	
Objective	To reduce external dose in the area
Other Benefits	
Countermeasure description	The contaminated roof covering is replaced with new or cleaned slates/tiles. This countermeasure is expensive, and labour intensive, and should only be considered as a last resort.
Target	Contaminated roofs of residential or industrial buildings. Clay tiles fired at low temperatures (< ca. 800°) may be considered as these would be particularly difficult to decontaminate.
Targeted radionuclides	Caesium.
Scale of application	Can be carried out on highly contaminated roofs in residential or industrial areas if new roofing materials are or can be made available.
Contamination pathway	None
Exposure pathway	External exposure.
Time of application	Should generally be carried out as early as possible, when the radiological situation is clear, but worker doses must be considered. May still after a decade save a significant fraction of the 70 y dose, depending on roof material and removable debris/growth.
Constraints	
• Legal constraints	Cultural heritage protection, especially in conservation areas or equivalent. Local authority liabilities for possible damage to property. Ownership and access to property. Possible health and safety regulations or equivalent preventing people from changing their own roofs (as self-help). Requirement for radiation protection training of workers.
• Social constraints	Aesthetic consequences of architecture changes
• Environmental constraints	
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of areas for treatment. Need for dialogue between owners/workers/public.
Effectiveness:	
• Countermeasure effectiveness	Complete removal of contamination from the roof covering.

• Factors influencing effectiveness of procedure (Technical)	Dependent on the time of application after the contamination, and the nature of the roofing material, a (usually small) fraction of the contamination may however have penetrated into the underlying (wooden) construction.
• Factors influencing effectiveness of procedure (social)	Correctness of application of the countermeasure
Feasibility:	
• Required specific equipment	New roofing materials (e.g., tiles, slates or roofing-felt). Depending on the type of roof-surface that is to be applied, hammers, cutters, and tools for extracting nails may be needed.
• Required ancillary equipment	Plastic sheets or tarpaulins to protect from any rain when the countermeasure is being carried out. Scaffolds or mobile lifts. Transport truck for new roofing materials, as well as for waste to repository, and machinery for constructing repository must be available.
• Required utilities and infrastructure	Transport roads.
• Required consumables	Petrol for transport vehicles.
• Required skills	Workers would ideally be professional roof workers. The job could however also be carried out by e.g., the civil defence, after little instruction.
• Required safety precautions	Lifeline. Safety helmets. Safety boots. Respiratory protection may be called for if the process generates dust. Should not be carried out as self help, because of the risk of falling from the roof.
• Other limitations	
Waste:	
• Amount and type	Large amounts (typically ca. 20-50 kg m^{-2}), dependent on type of roof to be removed. Normally very low specific activity. Caesium is strongly bound to e.g., slate, clay and concrete materials.
• Possible transport, treatment and storage routes.	Transport by e.g. trucks or rail, depending on waste action scheme. Simple repositories should be constructed. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential.
Doses:	
• Averted dose	Highly dependent on environment type. See separate Chapter.

• Factors influencing averted dose	Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over a large area. Also roof gutters and drain pipes should be renewed. Industrial buildings often have light (not well shielding) roof constructions, and the often little slope of the roof may give relatively high contamination level.
• Additional dose	Depends on short-lived radionuclides (time). The dose over a day to an operator may be 2-3 times higher than that to an individual living in the contaminated area (possibly even more, depending on roof height, landscape, etc.).
Intervention Costs:	
• Equipment	Roofing materials (ranging from clay or concrete tiles at ca. 15 EURO m^{-2}, to roofing felt at ca. 0.5 EURO m^{-2}). Comparatively small costs per area for tools. Plastic cover ca. 0.2 EURO m^{-2}.
• Consumables	Variable costs for petrol for equipment and waste transport, all at current prices.
• Operator time	Estimated to ca. 0.3-0.5 h m^{-2} for each of 2 workers, excl. setting up scaffolding, waste transport and work at repository.
• Factors influencing costs	Distance to equipment and consumables. Height of building. Types of roof covers to be removed and applied. Type and size of scaffolds /mobile lifts. Operator skills. Labour costs.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators on correct application of countermeasure. Dialogue costs re selection of areas for application of countermeasure.
• Compensation costs	Public/owner compensation for possible damage/change to property/amenity. Labour costs may be higher to compensate workers for their exposure to higher risks.
• Waste cost	-
• Assumptions	Availability of the required roads for transport of equipment, availability of new roofing materials.
Side-effect evaluation:	
• Ethical considerations	Redistribution of dose from users of urban spaces to operators and populations around waste facilities. Potential for self-help. Free informed consent of workers. Consent of public/private owners. Compensation for property/amenity damage/change.
• Environmental impact	-
• Agricultural impact	-

• Social impact	Maintenance of use of urban spaces Acceptability and potential for dispute regarding basis of selection of areas to be treated. Potential social divisions exacerbated between 'haves' and 'have nots', and/or stigma. Potential for dispute regarding waste disposal sites. Large positive impact on roofing industry.
• Other side effects, pos. or neg.	Improvement of the general state of the building, depending on the quality of the new roofing material. Public reassurance issues.
Practical experience	Tested on realistic scale on selected roofs of different types in the CIS, after the Chernobyl accident.
Key references	Roed et al.: Risø-R-870; Roed et al.: Risø-R-828; Hubert et al.: EUR 16530.
Comments	

2.5 Countermeasures for reduction of dose from contaminated indoor surfaces

Intensive indoor surface cleaning	
Objective	To reduce external dose in the area
Other Benefits	To reduce contaminant aerosol concentration in the breathing zone.
Countermeasure description	Dose contributions from indoor contamination may, if deposition to the area occurs without precipitation, be comparatively significant, especially over the first year. Also over longer periods, contamination may be brought into dwellings, e.g., on the soles of shoes. The countermeasure is essentially vacuum-cleaning of carpets/door mats and washing uncovered floors thoroughly and regularly. Also dusting of other surfaces may affect dose somewhat.
Target	Contaminated indoor surfaces of residential or industrial buildings. Especially floors, as most of the initial airborne contamination and nearly all secondary contamination (e.g., brought in under the soles of shoes) will deposit here.
Targeted radionuclides	Particularly caesium.
Scale of application	Can be carried out on a large scale in residential / industrial areas.
Contamination pathway	None
Exposure pathway	External exposure. Secondarily, also inhalation of resuspended indoor dust particles.
Time of application	Should generally be initiated as early as possible, when the radiological situation is clear, but worker doses must be considered. Floors should in heavily contaminated areas be cleaned regularly over years.
Constraints	
• Legal constraints	Restrictions on chemical use. Local authority liabilities for possible damage to property. Ownership and access to property. Requirement for radiation protection training of workers.
• Social constraints	Acceptability and potential for dispute.
• Environmental constraints	-
• Communication constraints	Need for public explanation of countermeasure and dialogue regarding selection of and responsibility for areas for treatment. Need for dialogue between owners/workers/public.

Effectiveness:	
• Countermeasure effectiveness	Vacuum cleaning of carpets / dusting will generally have insignificant effect on concentrations of contaminant particles of the ca. 1 µm range (as observed with the initial caesium contaminant particles after the Chernobyl accident). However, a fraction of the contamination will rapidly become attached to larger house dust particles (>5 µm), for which vacuum cleaning/dusting can be highly efficient (reduction by 90 %+). Soil particles brought in on shoes or by wind will be relatively large (easy to remove). Washing of floors: removal of ca. 35-65 %.
• Factors influencing effectiveness of procedure (Technical)	Care taken to vacuum/wash thoroughly over the entire floor. Time after the deposition (size and chemical reactivity/ fixation of contaminant particles). Type of vaccum-cleaner (preferably equipped with efficient outlet filter to prevent resuspension). Cleaning detergents. Type of carpet/ other surface. Dust loading at the time of deposition. Frequency of cleaning.
• Factors influencing effectiveness of procedure (social)	Compliance (owners/workers/public) with appropriate process of application of countermeasure. Extent of take-up at local/household level as self-help measure.
Feasibility:	
• Required specific equipment	Vacuum cleaner. Cloth.
• Required ancillary equipment	Cleaning detergent.Means of transport of waste to temporary storage or repository.
• Required utilities and infrastructure	Transport roads.
• Required consumables	Petrol for transport vehicles.
• Required skills	Can be carried out by local inhabitants (self-help initiative).
• Required safety precautions	Respiratory protection may be called for in highly contaminated areas. Water-proof plastic gloves for washing.
• Other limitations	
Waste:	
• Amount and type	Contaminated filters (variable, but generally high specific activity). Rough estimate of amount: some 40 g m^{-2} per year. Contaminated washing/ dusting cloth. Contaminated washing water can be led to the drains.

• Possible transport, treatment and storage routes.	Transport by e.g. trucks or rail, depending on waste action scheme. Simple repositories should be constructed. See separate Chapter for further information.
• Factors influencing waste issues	Public acceptability and legal feasibility of waste treatment and storage route are essential.
Doses:	
• Averted dose	See separate Chapter.
• Factors influencing averted dose	Ventilation rate and deposition rate (influenced by furniture) at airborne contaminant deposition. Population density and behaviour pattern. Age of persons exposed. Consistency in carrying out the procedure over the whole dwelling. Human (or animal) activities in the dwelling (influencing amounts and types of house dust particles).
• Additional dose	Particularly immediately after deposition increased inhalation doses may be received from resuspended particles. Not all types of respiratory protection will be very efficient for small particles.
Intervention Costs:	
• Equipment	Ordinary household vacuum cleaner (ca. 200 EURO). Cloth (ca. 1 EURO).
• Consumables	Ca. 4 filter bags per 100 m^2 per year, and variable costs for water, cleaning detergent and petrol for waste transport, all at current prices.
• Operator time	Vacuuming: Of the order of ½ minute per m^2. Washing: Of the order of 2-3 minutes per m^2. Additionally time for waste transport and work at repository.
• Factors influencing costs	Individual work rates, type of vacuum-cleaner.
• Communication costs	Provision of information for public on rationale for countermeasure. Information for operators/householders on application of countermeasure. Dialogue regarding responsibility for application of countermeasure.
• Compensation costs	Public/owner compensation for possible damage to property/amenity.
• Waste cost	Depends on choice of options (see separate Chapter).
• Assumptions	Water and power supply available.
Side-effect evaluation:	

• Ethical considerations	Redistribution of dose from users of indoor spaces to operators and populations around waste facilities. Self-help measure. Free informed consent of workers. Consent of public/private owners. Environmental consequences of waste generation and treatment (chemical and radioactive).
• Environmental impact	-
• Agricultural impact	-
• Social impact	Maintenance of use of indoor spaces. Acceptability and potential for dispute regarding waste disposal sites, and regarding prioritisation/selection of and responsibility for areas to be treated. Acceptability and potential for dispute between neighbours over different applications of countermeasure, and in relation to cultural expectations and traditions of household 'cleanliness'.
• Other side effects, pos. or neg.	Cleaning indoor surfaces of the building. Public reassurance issues. Gender conflict and marital dispute regarding responsibility to carry out countermeasure.
Practical experience	Several small-scale tests have been reported before/after the Chernobyl accident.
Key references	Report EUR 16604 EN; Roed: Relationships in indoor/outdoor air pollution, Risø-M-2476, 1985; Allott et al.: Atmosph. Env. 28(4), pp. 679-687, 1994.
Comments	Filters should not be changed too often, as old house dust in the filter has been found to increase filter efficiency for small particles. For 1 µm particles a filter retention of 97 % has been recorded.

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3 Disposal of wastes

This chapter gives a series of descriptions of possible routes of transport, treatment and storage/disposal of the wastes that may be generated by the described countermeasures. These text sections have been placed in this separate chapter as their required length made it impossible to directly accommodate them in the datasheets. Also, for instance, the routes of disposal of contaminated soil waste generated by various countermeasures would be the same and need only be described once.

3.1 Soil waste from urban areas

Waste constituted by removed radioactively contaminated soil (or soil mixed with lignin) may be very large in volume, and it is important that safe and cost-effective strategies for the disposal of such waste can be identified. Current legal demands may in some countries restrict the applicability of cost-effective strategies for waste disposal. It is important in the event of a major accident that any waste arising from decontaminating operations is regarded as an inherent part of the strategy for dose reduction.

Several safety aspects are of concern in connection with the establishment of a disposal site.

For instance, the waste depository must be constructed in a way that effectively prevents external radiation. Since the self-attenuation of radiation in soil is substantial, this problem can largely be overcome even with very simple repository designs. An example of this is the formation of simple, uncovered waste pile 'hills' in connection with a decontamination exercise in the Chernobyl-contaminated Novozybkov area in Russia in 1995 (Roed et al., 1996). The primary radionuclide of concern was here, as would be expected in connection with any major reactor accident, ^{137}Cs. It was found that the dose rate to a person standing on top of one of these hills containing contaminated topsoil removed from a vast area was only 15 % higher than that in the surrounding contaminated area. By covering the contamination with, e.g., a layer of uncontaminated soil excavated from deeper soil layers of the same area, this dose rate can be greatly reduced. Further, the formation of a 'hill' or bank of earth in the area will shield well against radiation from contamination far away. If a ^{137}Cs contamination is distributed in the upper ca. 2 cm of soil, about one-third of the dose rate to a person standing in a large, plane field will normally be expected to come from contamination more than 16 m away (Andersson, 1996).

The waste deposit must also be constructed in a way that prevents effectively against downward contaminant migration, e.g., to the groundwater. Several simple and inexpensive designs may be envisaged to take care of this. One such repository design, based on the recommendations of Junker et al. (1998) is shown in Figure 1. It is here ensured that there is a considerable distance from the bottom of the constructed repository to the groundwater level. A layer of clay or clayey soil will capture and retain many pollutants, especially caesium if it is leaking out of the waste storage area. A relatively thick plastic layer placed on top of the radioactive waste layer will prevent rainwater from reaching the contamination. In addition to this, a 0.3 m thick gravel layer is here applied to drain off rain water, and at the very top, a layer of fertile soil is placed. Vegetation grown in this layer will prevent against erosion, and the soil layer will at the same time (together with the other layers) add to the shielding against the external radiation from the buried contamination. A ditch should be dug around the repository, to collect drained-off rainwater. It is envisaged that this type of repositories could be constructed in as large scale as 400 by 400 metres.

Other, more simple designs have also been suggested and tested on a limited scale in Norway and in large scale in the former Soviet Union (Lehto & Paajanen, 1994). For instance, Salbu et al. (1994) suggested the formation of 10 m long and 3.5 m wide surface trench repositories with an arched top to enable rain water to easily run off into ditches at the sides of the trench. The trench was equipped with a drainpipe at the bottom for inspection of radionuclide content in water that had passed through the contaminated soil. The loss of radiocaesium from the soil waste area through rainwater migration was found to be very small, even for a peat soil, which is much less efficient in retaining caesium than is clay soil. Based on the work of Salbu et al. (1994), the total costs of disposal of contaminated soil (including worker salaries and use of machines) is estimated to be of the order of 2000-3000 Euro for each ha of land from which a topsoil layer of ca. 3-5 cm thickness is removed. The estimate assumes that repositories will be constructed in the contaminated area.

If other contaminants migrating more easily than caesium pose a problem, various stabilisation and solidification techniques can be applied to reduce this problem (Brodersen, 1993).

In constructing a repository it should further be ensured that the site will not be exposed to flooding (e.g., close to a river), and that the area is not prone to earthquakes. Old gravel pits should not be exploited for this purpose, as they will often provide too little distance to the groundwater.

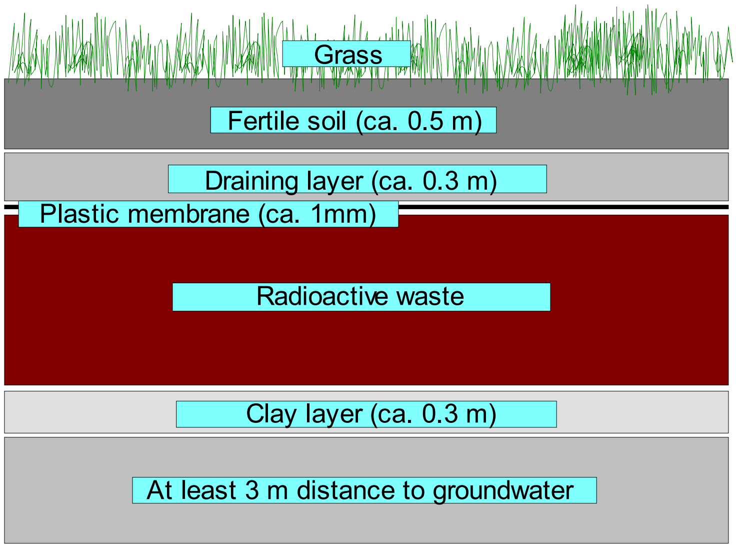

Figure 3.1 The principles of a suggested repository for radioactively contaminated waste (e.g., soil). Recommendations of Junker et al. (1998).

Waste repositories should generally be constructed in the contaminated areas, to minimise transport expenses. Thereby, also doses to transport workers can be minimised. Further, it will probably be considered most reasonable by the population that the repository problems are shared by the whole affected population rather than imposed massively on a specific selected part of the inhabitants living near a large, centralised repository.

Due to the self-attenuation of the soil, the external dose rate to workers is unlikely to differ greatly from that to other people spending time outdoors in the area. However, the amount of time spent outdoors will be likely to be comparatively great for these workers, and as buildings provide a (highly variable) shielding against radiation, the dose rate is expected to be significantly higher outdoors than indoors.

3.2 Contaminated biomass from urban areas

This type of waste may be grass or turf removed from a lawn or trees and shrubs removed from, e.g., gardens and park areas. Particularly the specific activity of grass may be high if the grass is cut early after a dry contamination has occurred. Also leaves on a tree or shrub may have high specific activity right after contamination. This problem and its impact on worker doses is described in detail under the heading 'additional dose' under the 'Lawn mowing' procedure description. Protection of workers may occur either through shielding with metal between the worker and the waste, by increasing the distance (e.g., by remote controlled operation) and/or limiting the number of individual work hours.

A number of methods may be envisaged to make use of some types of the removed biomass, depending on the contamination level. For instance, aerobic degradation (composting) will produce material that may be useful for soil fertilising, whereas anaerobic degradation produces gas that may be used in energy production. Core wood from contaminated trees may, particularly early after an accident, where the contamination will largely be confined to the outer surface, be applied in industry, e.g., for making furniture. The IAEA have prepared a report, which provides estimates of the conversion factors between biomass (wood) contamination levels and annual doses that would be received due to the contamination, assuming conditions that are believed to adequately reflect 'typical' situations (Balonov et al., 2003). In ICRP publication 82 (1999) it is recommended that the annual individual dose contribution from these sources does not exceed 1 mSv. However, it should be stressed that intervention exemption levels in use currently vary widely between countries, and may be considerably lower than the recommended 1 mSv limit.

The wood pulping process in connection with paper manufacturing may significantly reduce the contamination in the paper product. A special wood pulping treatment has been described by Roed et al. (1995) giving a decontamination factor of as much as 50-100.

An option for comparatively strongly contaminated wood, wood waste and other biomass (e.g., shrubs) is to chip it and combust it in safely designed power plants, which provide adequate protection of workers as well as of the environment. Thereby, energy is generated and at the same time the mass of the waste would be reduced by a factor of 10-100 by combustion. The technology required to produce energy from biomass is long established. In more forest-intensive European countries, such as Finland, wood combustion accounts for approximately 19 % of the energy consumption (15 % large scale and 4 % small-scale wood firing).

The magnitude of stack releases from a combustion plant depends on the boiler temperature as well as on the applied aerosol filter type. For instance, Mustonen et al. (1989) reported that four Finnish plants equipped with electrostatic filters for fly ash precipitation were found to have aerosol collection efficiencies (mass) in the range between 71 % and 99.7 %. According to Hedvall et al. (1996), Swedish biomass-fuelled power plants emit between 1.4 % and 10 % of the caesium in the applied Chernobyl-contaminated fuel to the atmosphere from the stack in the form of flue gas. Such releases may be greatly reduced by applying a baghouse filter. An efficient baghouse filter design has been proposed by Junker et al. (1998), essentially consisting of eight modules, each with 250 GORE-TEX membrane needle felt filter bags (each being 6 m long and having a surface area of about 2 m^2) and a hopper for collection of fly ash removed from the filters.

At an operating biomass combustion plant in Rechitza, Belarus, a filter of this type has been tested (Roed et al., 2000). The boiler was, prior to the test, not equipped with any flue gas treatment system. For the test, a cyclone filter was constructed which the flue gas from the boiler would pass through before entering the bag filter. This was to reduce the total mass of the flue gas dust, and at the same time prevent sparks from reaching the bag filter. From the bag filter the flue gas was led to the 70 m high stack, from which it was released to the atmosphere.

Aerosol laser spectrometry measurements showed, as was expected, that the cyclone had rather little effect on the smaller particles. The cyclone was found to have removed less than half of the caesium in the flue gas. However, measurements revealed that only some 0.5 % of the caesium in the original flue gas was left after the baghouse filter.

If one megatonnes of biomass with a specific activity of 500 Bq kg^{-1} were combusted annually in a plant releasing as much as 10 % of the caesium in the fuel to the atmosphere, this would be expected to lead to an integrated dose over a life-time to individuals 1 km from the power plant of *only some* 20 μSv (Junker et al., 1998). As pointed out above, this could be further greatly reduced by installing a baghouse filter.

Doses to workers at a power plant fired with contaminated biomass have been investigated in detail, assuming a typical bio-energy power plant construction (Andersson et al., 1999). It was concluded that if people are working throughout an entire working year only ½ m away from the locations at the power plant with the highest dose rate (which would grossly over-estimate the worker dose), annual doses of 2-3 mSv can be expected if the biomass (wood) is taken from an area contaminated by ca. 1 MBq m^{-2} of ^{137}Cs. Inhalation doses received at the plant through routine operation were found to be negligible. The maximum doses received at the power plant are received near concentrations of contaminated ash, as this is where the specific activity is highest. Doses to ash transport workers and workers at an ash repository would be expected to be of the same order of magnitude as the highest doses received at the power plant. In any case, worker doses should be assessed/minimised.

According to the recommendations of Junker et al (1998), the ash from combustion can be disposed of in thick plastic 'big bags' with typical volumes of ca. 2 m^3. These are placed in a ground repository of the type described for disposal of contaminated soil (see section 3.1). Without combustion, the biomass repositories would need to be 10-100 times bigger, and the wood would still need to be chipped.

Also spreading of ash for fertilising fields has been suggested. The fertiliser may in some soils significantly reduce contaminant uptake to plants, and the total effect could thus reduce dose, depending on the ash contamination level. The legality and acceptability of this (or any other) solution should of course first be assessed.

Current legal demands may in some countries restrict the applicability of cost-effective strategies for waste disposal. It is important in the event of a major accident that any waste arising from decontaminating operations is regarded as an inherent part of the strategy for dose reduction.

3.3 Contaminated cloths and vacuum-cleaner filters from indoor cleaning in urban areas

The effect of cleaning procedures applied on indoor surfaces may be significant, particularly early after a contamination has occurred. The specific activity of dust collected in vacuum-cleaner filters or on cloths may vary greatly, mainly depending on the deposition mode (if contamination occurs in heavy rain, indoor contamination will generally not constitute a problem at all) and contaminant particle size (Roed, 1985). The contamination level in the vacuum-cleaner filters should in very heavily contaminated areas be assessed prior to disposal. If the contamination level exceeds the maximum permissible level, this waste should be collected, e.g., in thick polypropylene bags, which may be disposed of in repositories in the ground (see section 3.1). The waste may in some cases have relatively high specific activity, and worker doses in connection with disposal should be assessed/minimised.

Current legal demands may in some countries restrict the applicability of cost-effective strategies for waste disposal. It is important in the event of a major accident that any waste arising from decontaminating operations is regarded as an inherent part of the strategy for dose reduction.

3.4 Contaminated snow from urban areas

Removal of snow in an urban or industrial area may lead to extremely large amounts of waste (Qvenild & Tveten, 1984). It would generally not be considered realistic in practice to melt all this snow and extract the contamination, although simple filtration designs would be expected to have a large effect. Alternatively, the snow masses may be dumped in the vast oceans, where the impact on the ecosystem would be considered to be limited. It should be ensured that the snow is not disposed of in, e.g., lakes where the waste may give rise to significant sediment contamination problems or lead to contamination of drinking water. As the snow may thus need to be transported over large distances, the transport expenses will often be high.

Current legal demands may in some countries restrict the applicability of cost-effective strategies for waste disposal. It is important in the event of a major accident that any waste arising from decontaminating operations is regarded as an inherent part of the strategy for dose reduction.

3.5 Contaminated roof pavings from urban areas

Contaminated roof pavings removed from a roof to reduce dose are likely to be of those types that are most efficient in retaining the deposited contamination. Clay, concrete and slate roofing materials may all contain significant amounts of mica, which can strongly bind caesium. If these materials were manufactured by firing at high temperature (> ca. 1200 °C), or, e.g., coated with silicon, the fixation of the contamination is, however, not nearly as great (Andersson et al., 2002). Roofing materials, to which caesium is strongly bound may be stored in piles in a restricted area without significant risk of contaminant migration. Simple ground repositories of the type suggested for contaminated soil waste (see section 3.1) may be recommended, depending on the contamination level. Legal demands concerning toxicity of asbestos materials must be taken into account in connection with handling and disposal of the waste. Costly vitrification processes have been suggested for increasing the water resistance of asbestos (Inaba et al., 1999), but simpler solutions would be recommended, of the type suggested for disposal of, e.g., fly ash from combustion (see section 3.2).

Current legal demands may in some countries restrict the applicability of cost-effective strategies for waste disposal. It is important in the event of a major accident that any waste arising from decontaminating operations is regarded as an inherent part of the strategy for dose reduction.

3.6 Waste from roof cleaning in urban areas

Solid waste removed by roof cleaning methods may include loosened particles from the roof materials, sludge (e.g., from the roof gutter, which would also be decontaminated), algae and moss. Many of these materials will normally retain contamination (particularly caesium) well, and the volume of this solid waste will thus be difficult to reduce by extraction. The waste will often arise from wet roof treatment procedures. Here, the solid waste will initially be present in usually large volumes of water, but can be easily removed by simple filtration, as practically all contamination has been found to be associated with the solid part of the waste (Fogh et al., 1999). If the waste will go to the sewer system then it will be collected in the sewage sludge. The specific activity of this waste will however be smaller than that of the rest of the sewage sludge, so that no special action has to be taken.

For filtration, a filter material that has been successfully tested in practice (for water containing contaminants) is the commercially available polymer fibre textile called 'TYPAR', with a pore size of 0.14 mm. The cost of this material is only ca. 0.50 Euro per m^2 (Roed et al., 1996). If the waste water from operation of a roof cleaning device on a mainly caesium-contaminated roof is filtered *in situ,* the water will be sufficiently clean of contamination to allow recycling in the decontamination operation (Roed et al., 1996). In practice the cleaning and recycling of water may be carried out through very simple means. Roed et al. (1996) described a set-up, where the waste water from cleaning a roof was collected in the roof gutter and led through a down-pipe into a large vessel. Inside this vessel, a plastic coated metal net was covered with 'TYPAR', which only the liquid fraction of the waste could penetrate. On the other side of the filter the water was pumped into another vessel, from which it could be recycled for the roof-cleaning operation (see Fig. 1).

Figure 3.2 Simple set-up for filtration of waste water from roof cleaning in Belarus.

The dry waste should be collected, e.g., in thick polypropylene bags, which may be disposed of in repositories in the ground (see section 3.1). The waste may in some cases have relatively high specific activity, and worker doses should be assessed/minimised. Legal demands concerning toxicity of asbestos materials must be taken into account in connection with handling and disposal of the waste.

Current legal demands may in some countries restrict the applicability of cost-effective strategies for waste disposal. It is important in the event of a major accident that any waste arising from decontaminating operations is regarded as an inherent part of the strategy for dose reduction.

3.7 Asphalt waste from urban areas

Removed contaminated asphalt will generally only be contaminated on the exposed surface. The migration of contaminants into bitumen (and concrete) has been reported to be negligible (Andersson, 1991). If it is not possible to efficiently remove the surface dust layer, to which the contamination will largely be confined, removal of asphalt surfaces, e.g., by planers, may generate rather large volumes of waste.

One way of dealing with this waste would be to bury it in repositories similar to those suggested for storage of contaminated soil (see section 3.1), which must provide sufficient safety both in relation to radiation and toxicity. Over very long time periods both aerobic and anerobic degradation of bitumen has been recorded (Roffey & Norqvist, 1991).

A much more inexpensive possibility would be to mix the removed, often not very strongly contaminated asphalt with new asphalt, as would be in-line with common practice in the asphalt industry, and re-use it for road paving. Naturally, the possibilities for re-use depend on the contamination level, but the dilution with new asphalt as well as the radiation attenuation by incorporation of the contamination in the whole asphalt mass rather than having it confined to the surface will greatly reduce the dose rate above the asphalted surface. A limiting factor for this option is likely to be public acceptability. Also the local legality of the solution must be assessed. The choice of method also depends on the size of the affected area.

Current legal demands may in some countries restrict the applicability of cost-effective strategies for waste disposal. It is important in the event of a major accident that any waste arising from decontaminating operations is regarded as an inherent part of the strategy for dose reduction.

3.8 Street dust waste from urban areas

Since contamination on streets is largely confined to the thin street dust layer (Andersson, 1991), removed street dust can have high specific activity. It is therefore important that workers at a disposal site, as well as transport workers, are adequately protected against the radiation from this type of waste. Calculations have shown that in an area with a contamination level of 1 MBq m^{-2}, containers of street dust may give a dose rate to operators (drivers) of 50-100 $\mu Sv\ h^{-1}$ (Ulvsand et al., 1997). Further, modern vacuum sweepers are often equipped with a water tank in which the dust is collected. This type of vacuum sweeper is preferable, as the water attenuates the radiation from the contamination in the collected dust. Protection of workers may occur either through shielding with metal between the worker and the waste, by increasing the distance (e.g., by remote controlled operation) and/or limiting the number of individual work hours.

Disposal of street dust may occur in a repository similar to those suggested for storage of contaminated soil (see section 3.1). It has been shown (de Preter, 1990) that the number of highly selective caesium sorption sites in street dust, which to some extent originates from erosion and weathering of urban surfaces, did not differ greatly from what was found in, e.g., micaceous tile samples. In other words, the same mechanisms in mica that strongly bind and retain particularly caesium in the soil are generally responsible for strong fixation also in street dust. This means that downward migration of caesium ions in a street dust layer will be very limited. If other contaminants migrating more easily than caesium pose a problem, various stabilisation and solidification techniques can be applied to reduce this problem (Brodersen, 1993).

Current legal demands may in some countries restrict the applicability of cost-effective strategies for waste disposal. It is important in the event of a major accident that any waste arising from decontaminating operations is regarded as an inherent part of the strategy for dose reduction.

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4 External dose in the urban environment

4.1 General methodology

In this chapter estimates are given of the external doses that individuals or populations would receive if they were staying in a ^{137}Cs contaminated urban area. Three different types of urban environment with different population densities were considered: semi-detached two-storey houses, rows of two-storey terrace houses and multi-storey blocks of flats. Each environment structure is described by a central building surrounded by buildings of the same type. Beyond the immediately surrounding buildings it was assumed that there were lawns.

Using a Monte Carlo code the exposure field was determined in a number of representative 'evaluation locations' where persons may be present indoors and outdoors in/around the central building of each environment (Meckbach et al., 1988). Based on assumptions regarding the time that persons would be considered to spend in each evaluation location, dose rates to inhabitants in the area can be estimated.

The described methodology enables integration of dose contributions from each of the various contaminated 'intervention elements' (surfaces such as roofs, walls, garden soil areas, trees and streets) in the environment over different periods of time. The dose that can be averted over a period of time by implementation of a countermeasure on an intervention element at a specific time can be estimated by multiplying the contribution to dose over the period from the contamination on the intervention element by the achievable fractional dose rate reduction (given under the heading 'Countermeasure Effectiveness' in the relevant datasheet).

4.1.1. Kerma estimates

Based on Monte Carlo photon transport calculations, the contributions of the various contaminated intervention elements to the air kerma per photon per unit of area at the various evaluation locations ($k_{sur,loc}$) were calculated and reported relative to a reference air kerma per photon per unit of area at a height of 1 m above an idealised, smooth, infinite ground surface, which is surface-contaminated with ^{137}Cs . Naturally, this reference value depends on the composition and density of air and soil used in the calculations. Tables 4.1-4.6 and Figures 4.1-4.3 show the characteristics of the three different types of environment as well as calculated values of $k_{sur,loc}$.

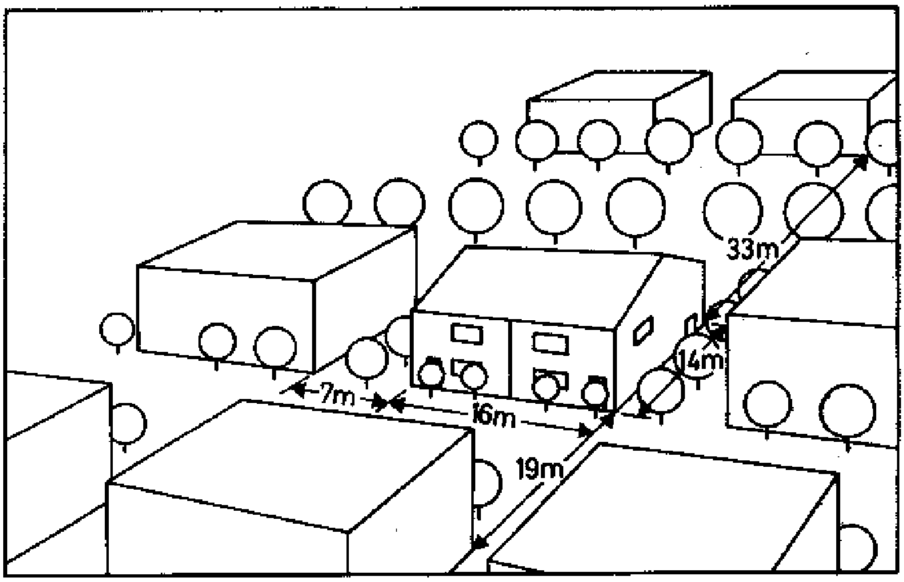

Figure 4.1. Urban environment with semi-detached houses.

Table 4.1. Construction details of the buildings and their surroundings studied in urban environment

(Semi-detached houses)

a, Semi-detached house (two stories)	
External walls	11.2 cm brick, 5 cm air, 11.5 cm breeze-block
Internal walls	Load bearing walls: 22 cm brick
	Partitioning walls: 10 cm concrete
Floors	Ground floor: 20 cm concrete
	First floor: 2.2 cm wood, 1.1 cm plasterboard
	Attic: 1.2 cm wood, 1.5 cm plasterboard
Roof	2.4 cm tiles
Windows	0.4 cm glass (windows fraction 12 %)
Basement type	Below ground level, external wall: 30 cm concrete, no windows
b, Area surrounding the buildings: plane garden areas with trees	
Garden areas	30 – 50 cm soil
c, Material densities ($g.cm^{-3}$)	Air 1.293×10^{-3}; soil 1; concrete 2.3; brick 1.8; breeze-block 0.96; wood 0.6; gypsum 1.0; plasterboard 0.96; glass 2.5; glass-wool 0.022; tiles 1.92;

The neighbouring buildings were simulated as simple unstructured boxes, the trees as spheres.

Table 4.2. Relative contribution of the various deposition areas to the air kerma per photon per unit area at the evaluation locations inside and outside the semi-detached house

Deposition area	Relative air kerma at the evaluation locations ($k_{sur,loc}$)						
	Basement	Ground floor	First floor	Attic	Outside, side	Outside, back	Total
On the house:							
Windows	1.82E-4	1.81E-2	2.79E-2	6.79E-3	2.42E-3	2.30E-2	7.84E-02
Walls and doors	1.82E-4	2.42E-2	2.42E-2	1.82E-2	1.52E-1	1.12E-1	3.31E-01
Roof	8.85E-4	2.54E-2	7.52E-2	2.30E-1	2.79E-3	5.58E-3	3.40E-01
Without neighbouring buildings:							
Ground	1.45E-4	9.33E-2	8.12E-2	1.03E-1	7.88E-1	8.24E-1	1.89E+00
With neighbouring buildings:							
Ground	9.70E-5	5.82E-2	4.85E-2	6.91E-2	5.27E-1	7.09E-1	1.41E+00
Neighbouring buildings[1]	2.42E-5	1.21E-2	1.33E-2	2.67E-2	1.45E-1	4.36E-2	2.41E-01
Trees	4.24E-5	1.33E-2	1.02E-2	8.61E-3	7.39E-2	9.45E-2	2.01E-01

Reference air kerma: 825 pGy per $\gamma.mm^{-2}$ (1 m above an infinite, smooth air-ground interface)
Source energy: 662 keV

1: The contributions from the neighbouring buildings can be considered as if they came from the roofs of these buildings because after a deposition the roof has generally the greatest contributions to the air kerma rate among the structural parts of a building.

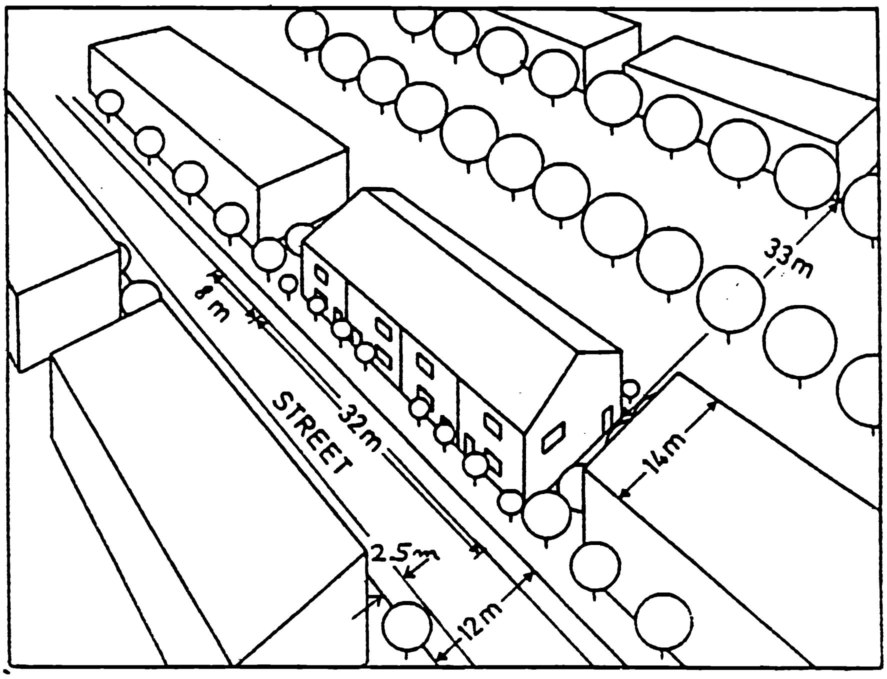

Figure 4.2. Urban environment with row of terrace houses.

Table 4.3. Construction details of the buildings and their surroundings studied in urban environment

(Row of terrace houses)

a, Row of terrace house	
External walls	11.2 cm brick, 5 cm air, 11.5 cm breeze-block
Internal walls	Load bearing walls: 22 cm brick
	Partitioning walls: 10 cm concrete
Floors	Ground floor: 20 cm concrete
	First floor and attic: 18 cm concrete
Roof	2.4 cm tiles
Windows	0.4 cm glass (windows fraction 14 %)
b, Area surrounding the buildings	
Plane areas with streets, walkways (park) and garden with trees	
Streets, walkways	10 cm concrete
Parks, garden areas	30 – 50 cm soil
c, Material densities ($g.cm^{-3}$)	Air 1.293×10^{-3}; soil 1; concrete 2.3; brick 1.8; breeze-block 0.96; wood 0.6; gypsum 1.0; plasterboard 0.96; glass 2.5; glass-wool 0.022; tiles 1.92;

The neighbouring buildings were simulated as simple unstructured boxes, the trees as spheres.

Table 4.4. Relative contribution of the various deposition areas to the air kerma per photon per unit area at the evaluation locations inside and outside the row of terrace house

	Relative air kerma at the evaluation locations ($k_{sur,loc}$)							
Deposition area	Base-ment	Ground floor	First floor	Attic	Outside, front	Outside, side	Outside, back	Total
On the house:								
Windows	1.21E-04	1.70E-02	1.82E-02	1.21E-04	1.21E-02	2.42E-03	2.79E-02	7.78E-02
Walls and doors	9.70E-05	1.58E-02	1.33E-02	6.18E-03	8.85E-02	1.58E-01	1.31E-01	4.12E-01
Roof	4.85E-06	3.03E-04	6.67E-03	2.59E-01	6.06E-03	1.82E-03	4.85E-03	2.79E-01
Without neighbouring buildings:								
Ground	7.27E-05	7.15E-02	4.00E-02	8.24E-02	8.12E-01	7.88E-01	7.64E-01	2.56E+00
With neighbouring buildings:								
Street	9.70E-06	8.85E-03	3.15E-03	1.82E-03	4.12E-01	2.55E-02	8.48E-04	4.52E-01
Gardens	3.64E-05	3.15E-02	1.21E-02	9.33E-03	1.88E-01	4.48E-01	6.18E-01	1.31E+00
Ground beyond neighbouring buildings	4.85E-06	4.85E-03	4.85E-03	3.64E-02	4.36E-02	3.03E-02	5.82E-02	1.78E-01
Walls and windows of neighbouring buildings	1.21E-05	7.52E-03	5.82E-03	8.97E-03	6.91E-02	1.70E-01	3.03E-02	2.91E-01
Roofs of neighbouring buildings	-	7.27E-04	1.09E-03	1.70E-02	8.48E-03	5.45E-03	5.45E-03	3.82E-02
Trees	3.03E-05	1.33E-02	7.27E-03	6.55E-03	5.33E-02	7.27E-02	9.94E-02	2.53E-01

Reference air kerma: 825 pGy per $\gamma.mm^{-2}$ (1 m above an infinite, smooth air-ground interface)
Source energy: 662 keV

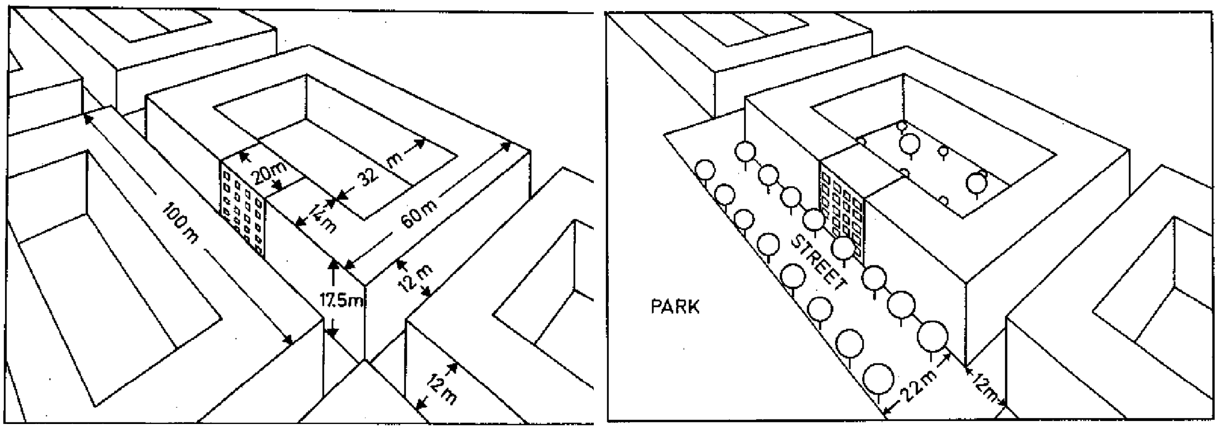

Figure 4.3. Urban environment with multi-storey house-blocks.

Table 4.5. Construction details of the buildings and their surroundings studied in urban environment

(Row of terrace houses)

a, Multi-storey house-block	
External walls	Outside wall: 30 cm brick
Internal walls	Load bearing walls: 22 cm brick
	Partitioning walls: 10 cm concrete
Floors	Ground floor: 30 cm concrete
	Other floors: 20 cm concrete
Roof	22 cm concrete
Windows	0.6 cm glass (windows fraction 15 %)
b, Area surrounding the buildings	
Plane areas with streets, walkways surrounded by other blocks or blocks with park and trees	
Streets, walkways	10 cm concrete
Parks, garden areas	30 – 50 cm soil
c, Material densities ($g.cm^{-3}$)	Air 1.293×10^{-3}; soil 1; concrete 2.3; brick 1.8; breeze-block 0.96; wood 0.6; gypsum 1.0; plasterboard 0.96; glass 2.5; glass-wool 0.022; tiles 1.92;

The neighbouring buildings were simulated as simple unstructured boxes, the trees as spheres.

Table 4.6. Relative contribution of the various deposition areas to the air kerma per photon per unit area at the evaluation locations inside and outside the row of terrace house

	Relative air kerma at the evaluation locations ($k_{sur,loc}$)						
Deposition area	Basement	Ground floor	Second floor	Fourth floor	Outside, street	Outside, courtyard	Total
On the building:							
Windows	1.09E-05	7.88E-03	7.88E-03	7.88E-03	1.94E-02	1.70E-02	6.00E-02
Walls	9.70E-06	2.55E-03	2.55E-03	2.42E-03	1.39E-01	1.08E-01	2.55E-01
Roof	-	-	1.21E-05	4.61E-03	3.64E-04	4.85E-04	5.47E-03
Courtyard	1.21E-05	6.18E-03	1.21E-03	6.06E-04	3.64E-04	6.42E-01	6.51E-01
Trees in courtyard	6.06E-07	1.09E-03	1.82E-04	7.27E-05	2.42E-05	2.55E-02	2.68E-02
With buildings across the street:							
Street	2.18E-05	3.15E-03	4.85E-04	1.82E-04	5.21E-01	4.85E-04	5.26E-01
Walls and windows of neighbouring buildings	5.09E-05	6.55E-03	6.42E-03	3.64E-03	3.27E-01	1.33E-01	4.77E-01
Roofs of neighbouring buildings	-	9.70E-05	1.82E-04	7.27E-04	3.64E-03	4.85E-03	9.49E-03
With parks across the street:							
Street	1.58E-05	4.73E-03	9.70E-04	3.64E-04	6.00E-01	6.06E-04	6.07E-01
Park	4.85E-06	5.82E-03	3.76E-03	2.67E-03	1.70E-01	4.85E-03	1.87E-01
Walls and windows of neighbouring buildings	2.91E-05	2.42E-03	2.42E-03	1.09E-03	8.24E-02	1.33E-01	2.22E-01
Roofs of neighbouring buildings	-	6.06E-05	9.70E-05	3.03E-04	1.82E-03	4.85E-03	7.13E-03
Trees in the street	1.58E-05	2.18E-03	3.88E-04	1.09E-04	6.30E-02	1.21E-04	6.58E-02

Reference air kerma: 825 pGy per $\gamma.mm^{-2}$ (1 m above an infinite, smooth air-ground interface)
Source energy: 662 keV

4.2 Application

The air kerma rate for a given photon energy, *E*, at an evaluation location due to an intervention element is the product of the air kerma per photon per unit area and the number of photons emitted per unit area and unit time from the surface. This latter is called source strength and can be obtained from measurements. The time dependence of the exposure field can be described by changes in the source strengths.

4.2.1. Reference source strength

The activity per unit area $A_{ref}(t)$ [Bq.mm^{-2}] at time t after the deposition can be described according to the decay law:

$$A_{ref}(t) = A_{ref}(0) \cdot e^{-(\lambda_r \cdot t)}$$

where $A_{ref}(0)$ is the deposited activity at t=0 and λ_r is the decay constant of the radionuclide considered. If we define the reference surface geometry as an infinite smooth air-ground interface (an idealized lawn) with the radionuclides deposited only on the ground (this means that there is no roughness of the surface and there is no initial penetration into the deeper layers) then the source strength $S_{ref}(E,t)$ [mm^{-2}.s^{-1}] of the photons of this radionuclide emitted with energy E per unit area and time can be defined according to Meckbach (1997):

$$S_{ref}(E,t) = S_{id}(E,t) = A_{ref}(0) \cdot e^{-(\lambda_r \cdot t)} \cdot y(E) = A_{ref}(t) \cdot y(E),$$

where $A_{ref}(0)$ is the initially deposited activity on an undisturbed lawn and $y(E)$ [s^{-1}.Bq^{-1}] is the yield of photons with energy E per decay.

4.2.2. Effective source strengths

The different surfaces in urban environment have different initial retentions compared to the reference surface and have different parameters for the function describing the long-term behaviour of the deposited material. This means that for describing the air kerma rate above the various surfaces we can use so called *effective* source strengths, $S_{sur}(E,t)$, where

$$S_{sur}(E,t) = S_{id}(E,t) \cdot s_{sur}(E,t) = S_{ref}(E,t) \cdot s_{sur}(E,0) \cdot w_{sur}(t)$$

and $s_{sur}(E,0)$ refers to the reduction of the source strength due to only partial initial retention (Roed 1987a; Roed and Jacob 1990), initial penetration and roughness of the surface compared to the idealised reference surface, and $w_{sur}(t)$ refers to the weathering and/or the long-term migration of the deposit. For each urban surface, *sur* with effective source strength, $S_{sur}(E,t)$ an effective source strength, $s_{sur}(E,t)$ *relative* to the reference source strength can be defined.

4.2.3. Long term behaviour

Summarising the results of measurements (Jacob et al. 1987; Roed 1987b; Roed and Jacob 1990; Jacob et al. 1990) the weathering processes and the effect of migration generally follow a two-class exponential behaviour with time. In this function there is a "mobile fraction", *a* with shorter half-life, *b* due to the loose binding to the surface or due to the higher migration rate (in the case of permeable surfaces) and there is a "fixed fraction", *(1-a)* with a longer half-life, *c* due to the strong binding to the surface or due to the lower migration rate:

$$w_{sur}(t) = a \cdot e^{-(b \cdot t)} + (1-a) \cdot e^{-(c \cdot t)}$$

where $w_{sur}(t)$ is the activity fraction retained after weathering for time t, and a, b and c are parameters for each surface (see Table 4.7.).

4.2.4. Relative effective source strengths of urban surfaces

The parameter values for the analytical approximation of the relative effective source strengths are summarised by Andersson et al. (2002), Andersson et al. (1995), Roed (1990) and Roed (1987 a,b) and shown in Table 4.7. The values presented here are considered to be 'best estimates', whereas actual values may vary depending on, e.g., materials, geometrical arrangements and weathering conditions.

The figures are generally smaller than one (except trees) and are characteristic for Western European conditions.

Table 4.7. Parameters describing the analytical approximation of the relative effective source strengths due to initial retention and subsequent weathering and migration from urban surfaces.

Surface	$s_{sur}(E,0)$ *dry*	$s_{sur}(E,0)$ *wet*	***a*** *mobile fraction*	$T_1=(\ln 2)/b$ *(year)*	$T_2=(\ln 2)/c$ *(year)*
Windows	0.01	0.01	0.8	0.2	2
Vertical walls	0.1	0.015	0.2	0.2	20
Roofs with tiles	0.7	0.7	0.5	1 – 4	25 – 50
Paved areas	0.4	0.55	0.5	0.2	2
Trees	3	0.1	0.8	0.2	2
Lawn[a]	0.9	0.7	0.46	1.5	50

[a] : $s_{sur}(E,0)$ relative to the idealised reference lawn (see above). In the case of dry deposition the value of 0.9 refers only to the surface roughness; in the case of wet deposition the value of 0.7 refers both to the surface roughness and initial penetration.

4.2.5. Air kerma rates from the idealised reference surface

The air kerma *rate* 1 m above the idealised reference surface, $\dot{K}_{ref}$ due to the radionuclide considered can be calculated by multiplication of the source strength of the reference surface $S_{ref}(E,t)$ by the air kerma per photon per unit reference area $K_{ref}(E)$ according to:

$$\dot{K}_{ref}\left[\frac{pGy}{s}\right]=S_{ref}(E,t)\left[\frac{\gamma}{mm^2\cdot s}\right]\cdot K_{ref}(E)\left[\frac{pGy}{\frac{\gamma}{mm^2}}\right]=A_{ref}(0)\cdot e^{-(\lambda_r\cdot t)}\cdot y(E)\cdot K_{ref}(E)$$

This formula is only valid for radionuclides which emit photons with one discrete energy, *E*. In the case of ^{137}Cs the photons with an energy of 662 keV are emitted with a yield of 0.85 $Bq^{-1}.s^{-1}$ and the air kerma per photon per unit reference area is 825 pGy per $\gamma.mm^{-2}$. The air kerma rate can also be expressed as

$$\dot{K}_{ref}=A_{ref}(0)\cdot e^{-(\lambda_r\cdot t)}\cdot g_{ref}\,,$$

where $g_{ref}\left[\frac{\frac{pGy}{s}}{\frac{Bq}{mm^2}}\right]=\sum_E y(E)\cdot K_{ref}(E)$ is the air kerma rate per unit activity per unit area (ICRU 1994).

4.2.6. Air kerma rates due to contaminated urban surfaces

In order to obtain the air kerma rate $\dot{K}_{sur,loc}$ at given location *loc* from a given surface *sur* the source strength of the surface $S_{sur}(E,t)$ has to be multiplied by the air kerma per photon per unit deposition area $K_{sur,loc}(E)$:

$$\dot{K}_{sur,loc}\left[\frac{pGy}{s}\right] = S_{sur}(E,t)\left[\frac{\gamma}{mm^2 \cdot s}\right] \cdot K_{sur,loc}(E)\left[\frac{pGy}{\frac{\gamma}{mm^2}}\right] =$$

$$= A_{ref}(0) \cdot e^{-(\lambda_r \cdot t)} \cdot g_{ref} \cdot s_{sur}(E,t) \cdot k_{sur,loc}(E)$$

4.2.7. Evaluation of doses

The *individual dose rate* at *one* evaluation location due to *one* intervention element (e.g. all roofs in the environment) to one member of a population group is:

$$\dot{ID}_{p,sur,loc}\left[\frac{pSv}{h}\right] = \dot{K}_{sur,loc} \cdot C_{p,loc} \cdot PT_{p,loc} \cdot 3600$$

$C_{p,loc}$: conversion coefficient from air kerma to effective dose for population group p at indoor or outdoor evaluation locations. [$Sv.Gy^{-1}$]

$PT_{p,loc}$: permanence time of the evaluation location by an individual from the population group p. [hours per day]

At any time instant these kerma rates can be calculated if the time dependence of the relative effective source strengths of the different surfaces are known. The *individual dose* at *one* evaluation location due to *all* intervention elements can be calculated in two steps: firstly, by separate integrations of the dose rates (assuming time independent permanence time and dose conversion coefficients) and secondly, by a summation over the surfaces, *sur*:

$$ID_{p,loc}[pSv] = C_{p,loc} \cdot PT_{p,loc} \cdot 3600 \cdot \sum_{sur} \int_i^f \dot{K}_{sur,loc}\, dt$$

The *collective dose rate* at *one* evaluation location due to *one* intervention element (e.g. all roofs in the environment) to a whole population group is:

$$\dot{CD}_{p,sur,loc}\left[\frac{person.pSv}{h}\right] = \dot{K}_{sur,loc} \cdot C_{p,loc} \cdot Oc_{p,loc} \cdot 3600$$

$Oc_{p,loc}$: occupancy of the evaluation location by the members of the population group p. [persons hours per day]

The air kerma rates are integrated over the time and summed over surfaces similarly as in the case of calculation of individual dose in order to get the total air kerma at an evaluation location. Summations over the evaluation locations and population groups will provide the *collective dose* from the whole environment.

The *dose conversion factors* used outdoor and indoor (Table 8.) were chosen according to Golikov et al. (1999). The *averted doses* can be calculated using the decontamination (DF) or surface dose reduction factors (DRF) considering the dose reductive efficiency of the selected countermeasures.

Table 4.8. Dose conversion factors used outdoor and indoor.

	Air kerma-effective dose conversion factor (Sv/Gy)	
Age group	**Outdoors**	**Indoors**
Adults >18	0.75	0.75
5 - 18 years	0.8	0.8
0 - 5 years	0.9	0.9

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5 Conclusions

The Chernobyl accident demonstrated that the consequences of radioactive contamination of inhabited areas can be severe and manifold. Over the years a large number of methods have been suggested and tested for reduction of these adverse consequences. It has been demonstrated that countermeasures exist, which can greatly reduce the external dose to urban populations. However, clearly also other aspects than dose reduction must be considered in connection with the formation of a countermeasure strategy for a contaminated area.

A series of investigations has been made of countermeasures that were deemed to be potentially applicable in member states of the European Union for reduction of dose in an urban complex contaminated as a result of a nuclear accident. The countermeasures were described in a uniform format accommodating a host of factors that may impinge on the justification and optimisation of the methods in nuclear preparedness. The level of detail in the countermeasure descriptions decisively advances them over other existing decision support databases.

Some of the suggested countermeasures produce waste, which must be disposed of in a way that is legal, safe and acceptable. The handling and disposal of this waste should be seen as an inherent part of a dose reduction strategy, and its costs, in directly assessable monetary as well as in social/health/psychological terms, should enter the matrix forming the foundation for decisions. Therefore, a series of descriptions of management options for the waste generated by the described countermeasures has been included in this report.

The doses that can be averted by the introduction of a countermeasure strongly depend on a number of case-specific parameters, including the type of contaminants, environment characteristics (e.g., wall thickness) and behaviour pattern of the population. Detailed calculations of dose contributions from each of the various contaminated surfaces in an urban environment are a necessary requirement in estimating the dose that can be averted by a countermeasure. The dose calculations in this report can also be used to demonstrate which types of surface contribute most to dose over any specified period to individuals or groups of people living in specified urban environment types. This is important in pinpointing where dose reduction is most needed in the particular case from a radiological viewpoint. In analysing countermeasure options it is generally convenient to balance the advantages against the disadvantages, e.g., in monetary terms. The valuing of averted dose and a number of other important implications of countermeasures is, however, to a great extent politically driven and case-specific.

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Physical countermeasures to sustain acceptable living and working conditions in radioactively contaminated residential areas

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Abstract (max. 2000 characters)

The Chernobyl accident highlighted the need in nuclear preparedness for robust, effective and sustainable countermeasure strategies for restoration of radioactively contaminated residential areas. Under the EC-supported STRATEGY project a series of investigations were made of countermeasures that were deemed potentially applicable for implementation in such events in European Member States. The findings are presented in this report, in a standardised datasheet format to clarify the features of the individual methods and facilitate intercomparison. The aspects of averted doses and management of wastes generated by countermeasures had to be described separately to provide room for the required level of detail. The information is mainly intended as a tool for decision makers and planners and constitutes a basis for the STRATEGY decision framework for remediation of contaminated urban areas.

Descriptors INIS/EDB

COST BENEFIT ANALYSIS; DECISION MAKING; DECONTAMINATION; EMERGENCY PLANS; RADIATION DOSES; REMEDIAL ACTION; SURFACE CONTAMINATION; URBAN AREAS; WASTE MANAGEMENT